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If you could imagine a place where life might exist within our galaxy, where would you think to look? Of course, terrestrial worlds that are a dead ringer for Earth - a so-called Earth 2.0 - could be a haven teeming with organisms, but what about those places submersed in liquid? This month you'll meet the ocean worlds and discover what secrets they hold.

These wet worlds can be found in our very own Solar System, and planetary scientists are shooting straight for them with the next generation of space missions, destined to unlock their true potential to hold life. As Morgan Cable, an astrobiologist at NASA's Jet Propulsion Laboratory, tells **All About Space**, the rules of physics and chemistry seem to apply everywhere, but we haven't tested this for biology yet. "If you have an environment with habitable conditions, and you wait long enough, will life emerge?" Cable poses to us. She also reveals how we might strike it lucky in the search for alien life over on page 14.

Speaking of life, and on the opposite side of the spectrum, we hope you stick around for next issue, where we dive deep into the new groundbreaking discovery of phosphine on Venus. Could biology alter so much that life forms thrive on its arid, heated and highly pressurised surface? I'll leave you with that thought. See you soon!

GEMMA LAVENDER

EDITOR-IN-CHIEF

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LAUNCH PAD

YOUR FIRST CONTACT WITH THE UNIVERSE





Meet the Meathook Galaxy

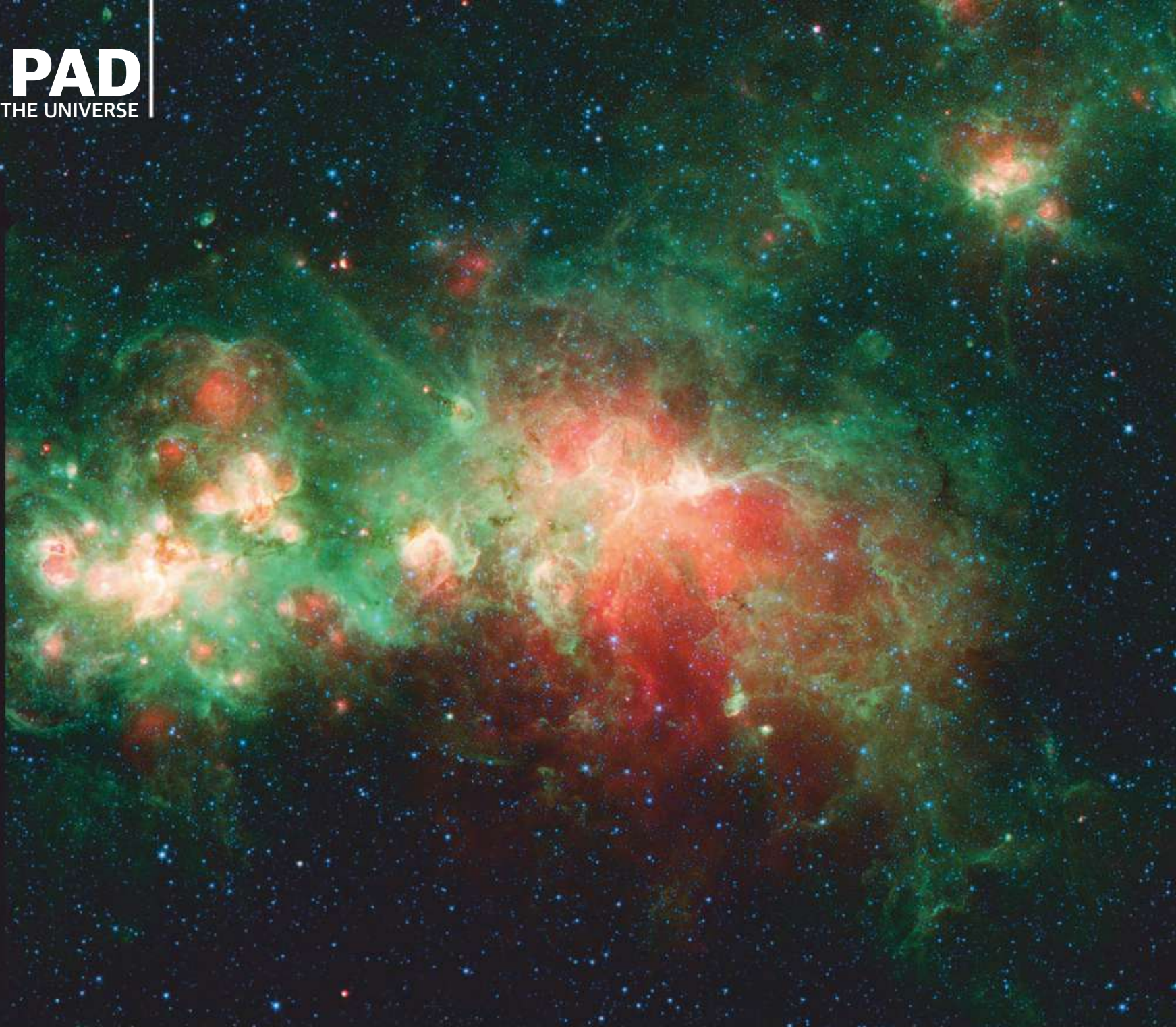
The long-serving Hubble Space Telescope continued to capture stunning sights of the universe throughout August and September. One fruit of its imaging surveys is this spectacular close-up of NGC 2442, also known as the Meathook Galaxy. The structure gets its nickname thanks to its asymmetrical and irregular shape.

In March 2015, the Meathook captured the attention of astronomers when one of its white dwarf stars exploded as a supernova, creating an eruption of light so dazzling it was visible from Earth for several months.

Spitzer sees a star factory in infrared

NASA's recently retired Spitzer Space Telescope was capable of revealing aspects of space invisible to the human eye. It was fixated on infrared, observing in a wavelength longer than visible light.

In this image, Spitzer honed in on 'star factory' and nebula W51, which is home to a plethora of baby stars in the process of creating planetary systems like our own. Starlight from these stellar youngsters is often blocked by surrounding gas and dust but Spitzer was able to see through it, revealing activity behind a cosmic curtain.



Space Station view over the Philippine Sea

Inhabitants of Earth can often gaze upon magnificent sights throughout the cosmos, but the one thing most of us can't do is gaze upon the beauty of our own planet from space. However, the lucky inhabitants of the International Space Station (ISS) can do just that.

This image was taken as the ISS flew approximately 320 kilometres (200 miles) over Earth, catching the sunrise hitting the clouds above the Philippine Sea and casting awe-inspiring shadows over the seemingly settled body of water.



The beauty of globular star clusters

On 7 September 2020, NASA released this sparkling addition to the expanding album of Hubble Space Telescope pictures. This beautiful array of colourful stars make up the globular star cluster NGC 1805, which is located near the Large Magellanic Cloud, a satellite galaxy to the Milky Way that's visible in the Southern Hemisphere sky.

The two main colours in this image correspond to different wavelengths of light. The blue stars were imaged in near-ultraviolet light, whereas the red stars were captured in near-infrared. Together they show a group of densely packed stars that create a very aesthetically pleasing portrait.

Earth may be influencing oxidation on the Moon with its magnetic field



New research finds that the Moon is rusty

Words by Yasemin Saplakoglu

The Moon is turning ever so slightly red, and it's likely Earth's fault. Our planet's atmosphere may be causing the Moon to rust. Rust, also known as iron oxide, is a reddish compound that forms when iron is exposed to water and oxygen. Rust is the result of a common chemical reaction for nails, gates, the Grand Canyon's red rocks - and even Mars. The Red Planet is nicknamed after its reddish hue that comes from the rust it acquired long ago when iron on its surface combined with oxygen and water.

But not all celestial environments are optimal for rusting, especially our dry, atmosphere-free Moon. "It's very puzzling," said Shuai Li, an assistant researcher at the University of Hawaii at Mānoa's Hawaii Institute of Geophysics and Planetology. "The Moon is a terrible environment for [rust] to form in." For iron to turn rusty red, it needs what's called an oxidiser - a molecule such as oxygen that removes electrons from a material such as iron. But the Sun's solar wind, a stream of charged particles that constantly hits the Moon with hydrogen, has the opposite effect. Hydrogen

is a reducer, or a molecule that donates electrons to other molecules. Without protection from this solar wind, such as the magnetic field that shields our planet from it, rust should not be able to form on the Moon.

The Moon doesn't have an atmosphere of its own to provide sufficient amounts of oxygen, but it has trace amounts donated by Earth's atmosphere. This terrestrial oxygen travels to the Moon along an elongated extension of the planet's magnetic field called a 'magnetotail'. Earth's magnetotail can reach all the way to the near side of the Moon, where hematite - a common iron oxide - was found. What's more, at every full Moon the magnetotail blocks 99 per cent of solar wind from blasting it, drawing a temporary curtain over the lunar surface and

allowing periods of time for rust to form. But there's still one extra ingredient that's needed for rust to form: water.

The Moon is mostly devoid of water, save for frozen water found in lunar craters on the far side - far from where most of the hematite was found. But the researchers propose that fast-moving dust particles that bombard the Moon might free water molecules locked in the surface layer, allowing the water to mix with the iron. These dust particles might even be carrying water molecules themselves, and their impact might create heat that could increase the oxidation rate. "This discovery will reshape our knowledge about the Moon's polar regions," Li said. "Earth may have played an important role in the evolution of the Moon's surface."

"NOT ALL CELESTIAL ENVIRONMENTS ARE OPTIMAL FOR RUSTING, ESPECIALLY OUR DRY, ATMOSPHERE-FREE MOON"

The Andromeda Galaxy's halo is more massive than initially thought

Words by Meghan Bartels

Galactic halos are both more massive and more complicated than scientists realised, according to new Hubble observations. The venerable telescope turned its sights on the neighbouring Andromeda Galaxy using dozens of different quasars to map the galactic halo. Andromeda, more formally known as Messier 31, is a spiral-shaped galaxy about the same size of the Milky Way we live in, with about 1 trillion stars. Cosmically it's right next door, just 2.5 million light years away, which means that Hubble can study its halo in unprecedented detail.

"This is truly a unique experiment because only with Andromeda do we have information on its halo along not only one or two sightlines, but over 40," said Nicolas Lehner, an astrophysicist at the University of Notre Dame in Indiana. "This is groundbreaking for capturing the complexity of a galaxy halo beyond our own Milky Way."

Researchers found that the halo itself stretched much farther across space than expected, a whopping 1.3 million light years out from the galaxy, and at some spots more like 2 million light years. If human eyes could see it, it would be three times as wide as the Big Dipper. In starker

terms, Andromeda's halo covers more than half the distance between Andromeda and the Milky Way, suggesting that the two halos intermingle. The research also found that the structure of Andromeda's halo is more complicated than expected, with two distinct layers. "We find the inner shell, that extends to about half a million light years, is far more complex and dynamic," Lehner said. "The outer shell is smoother and hotter."



Same black hole can collide with its kin multiple times, lopsided merger suggests

Words by Meghan Bartels

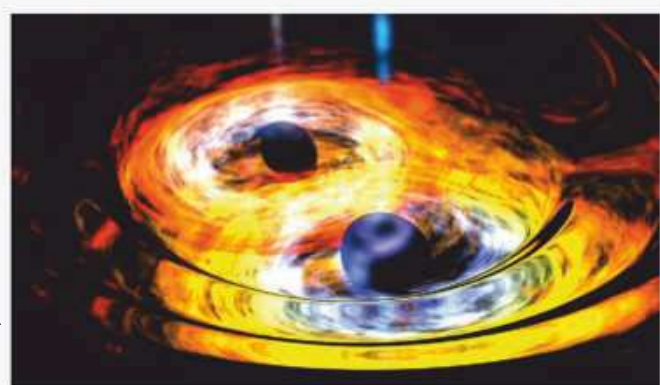
For black holes, a collision doesn't have to be a once-in-a-lifetime experience. On 12 April 2019, scientists detected a new black hole merger using a trio of gravitational-wave detectors. Astrophysicists have spotted such events before, but something about the signals was different: the two black holes that collided were incredibly unevenly matched, with the larger about three times the size of the smaller.

"This event is an oddball the universe has thrown at us - it was something we didn't see coming," said Salvatore Vitale, a physicist at the Massachusetts Institute of Technology. "But nothing happens just once in the universe. And something like this,

though rare, we will see again, and we'll be able to say more about the universe."

Vitale and his colleagues suspect that the strange collision occurred after the larger black hole itself was the product of a black hole merger. The initial event sent a large black hole bouncing around a neighbourhood packed with more black holes, enabling the uneven collision. That's a very different story than scientists' two main scenarios for black hole mergers, which both encourage fairly even matches. Vitale and his colleagues used two different models to evaluate whether the traditional merger scenarios could create an event like the unbalanced merger.

Scientists analysing the uneven collision suspect that hierarchical mergers couldn't happen just anywhere, but instead must occur in a relatively dense neighbourhood, where black holes can easily interact. "This merger must have come from an unusual place," Vitale said. "As LIGO [the Laser Interferometer Gravitational-Wave Observatory] and Virgo continue to make new detections, we can use these to learn new things about the universe."



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Earth may have been born wet Words by Mike Wall

Earth may not have needed asteroid and comet strikes to fill its oceans. Conventional wisdom has long held that our planet was born dry, because its building blocks formed relatively close to the hot, baking Sun. Earth therefore got the vast majority of its water later, most scientists believe, from impacting objects native to the cold and icy depths of the outer Solar System.

Researchers have been arguing for years about whether comets or asteroids were the primary water bearers. Researchers analysed 13 different enstatite chondrite meteorites, a class known to be similar to the space rocks that coalesced to form Earth. They found lots of hydrogen in the supposedly dry meteorites - enough to imply that our planet was born quite wet. The calculations suggest that the rocks that formed Earth harboured at least three times as much water as the planet's present-day oceans hold.



"Our discovery shows that Earth's building blocks might have significantly contributed to Earth's water," said Laurette Piani, a researcher at the Centre de Recherches Pétrographiques et Géochimiques in France. "Hydrogen-bearing material was present in the inner Solar System at the time of rocky planet formation, even though the temperatures were too high for water to condense."

Big questions remain about the timing of Earth's water uptake, so it's unclear if most of the water sloshing in our seas does indeed go all the way back. For example, if most of Earth's native water was incorporated very early on, it may have been boiled away by long-ago asteroid bombardments and/or the formation of magma oceans. "The research brings a crucial and elegant element to this puzzle," said Anne Peslier of NASA. "Earth's water may simply have come from the nebular material from which the planet accreted."

Above:
It's been accepted that Earth formed too close to the Sun to hold water

Scientists spot a triple star system shredding its planet-forming disc Words by Chelsea Gohd

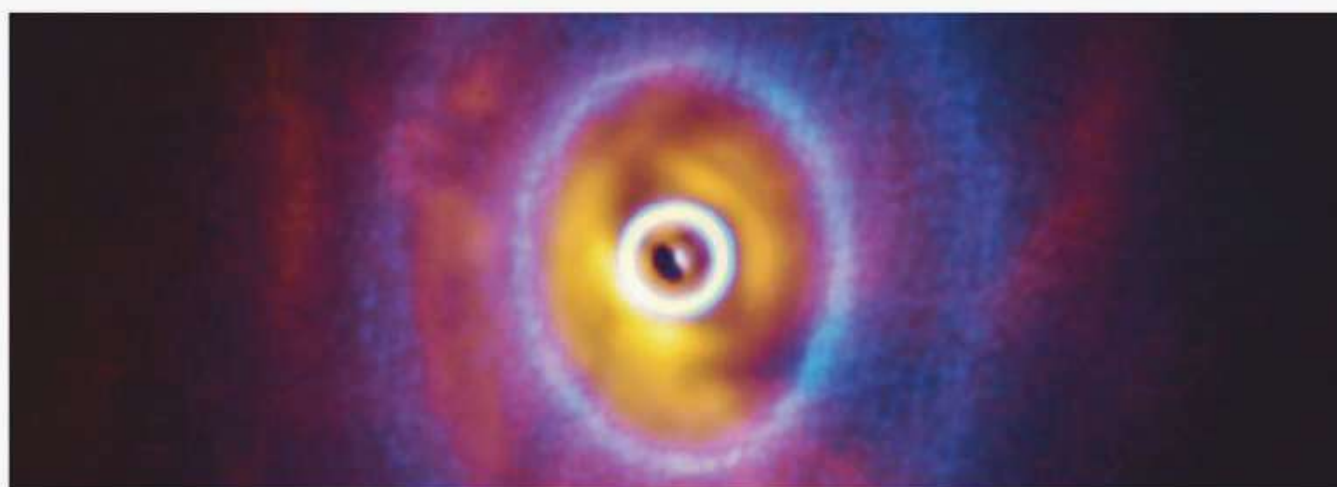
Groups of stars can tear their planet-forming disc to shreds, leaving behind warped, misaligned rings. Solar systems like ours generally form with their planets all orbiting in the same flat plane - but this isn't always the case. After 11 years studying GW Orionis, a young triple star system lying 1,300 light years away with a circumstellar disc, a team of researchers found the first direct evidence that groups of stars can actually tear apart their discs. This work reveals a disc that isn't flat at all, and is instead misaligned and broken.

"There have been a number of theoretical studies on disc-tearing effects, but this is the first direct evidence of the effect occurring in a planet-forming disc," said Alison Young of the University of Exeter, UK. "This demonstrates that it is possible for such discs to be warped and broken, and raises

the possibility that planets could form on highly inclined orbits around multiple star systems."

The warped ring, which is located in the inner part of GW Orionis' disc, contains 30 Earth masses of dust. This means that the disc contains enough material to form planets. "It's the best mechanism for forming planets on such extreme orbits to be found so far," said Stefan Kraus, a professor of astrophysics at the University of Exeter, referring to the warping observed in GW Orionis. "But from the planet-detection side, we don't have a way of detecting these planets yet."

While the researchers have yet to detect planets within this system, the study confirms what scientists have suspected for years: that multi-star systems can break their own discs, leaving inclined, misaligned rings around the stars.



Left: Multi-star systems have the potential to form planets off the usual orbital plane

Right: Muscle and bone mass are lost without the effect of gravity the body is used to

Buff space mice to stop astronauts losing bone and muscle mass

Words by Charles Q. Choi

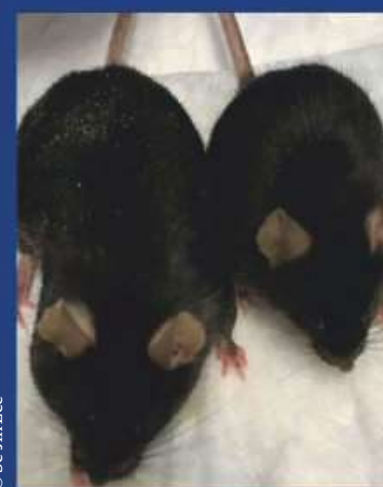
In December last year scientists launched 40 mice from NASA's Kennedy Space Center to the International Space Station (ISS) aboard SpaceX's CRS-19 cargo resupply services mission.

While 24 of the mice were normal, eight of them were missing the myostatin - a protein that normally limits muscle growth - gene and eight others were treated with a molecule that suppressed both myostatin and a protein known as activin A, which has similar effects on muscle as myostatin.

The normal mice - those that carried the myostatin gene and received no protein-inhibiting treatments - lost significant muscle and bone mass during the 33 days spent in microgravity.

In contrast, mice that were missing the myostatin gene, and had a muscle mass about twice that of a regular mouse, largely retained their muscles during spaceflight.

Scientists also found the mice that received the molecule suppressing myostatin and activin A saw dramatic increases in both muscle and bone mass.



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SECRETS OF THE OCEAN WORLDS

If physics and chemistry are the same
throughout the universe, is biology too?

Reported by Lee Cavendish

Earth isn't the only world which accommodates water. There are moons in the Solar System half the size of Earth that hold much more.

These are known as ocean worlds. Astronomers continue to scrutinise these in great detail, as they have the potential to change how biology is viewed throughout the universe. "An ocean world is any planet, or sometimes moon, that has at least ten times the amount of water that Earth does. For reference, Earth is about 0.1 per cent water, so an ocean world has a water content of one per cent or greater," explains Dr Lynnae Quick, an ocean worlds planetary scientist at NASA's Goddard Space Flight Center in Maryland, to **All About Space**.

Water is a necessity for life as we know it. Every living thing on Earth consumes water to stay hydrated and survive. Water also provides opportunities for exploration, whether it is taking to the oceans to discover a new bit of land or diving into the depths below, where many mysteries remain unanswered. Astrobiologists now want to up the ante and explore the oceans of other worlds millions of miles - or possibly even light years - away in order to find signs of alien life.

How worlds end up having global oceans, either visible on the surface or buried underneath an icy exterior, is a story in itself. Water does not float through space as liquid droplets waiting to splash down on a surface. As space is so cold, water travels through space as grains of ice. As new planetary systems begin to form around a young star, water can stay as these icy grains beyond a certain radius, known as the 'ice line'.

"There is a natural 'ice line' in the Solar System where volatile species migrated away from the centre, akin to a tree line on tall mountains. The outer Solar System is replete with water, among other such species," says Dr Chris German, a senior scientist at the Woods Hole Oceanographic Institution (WHOI) in Falmouth, Massachusetts. "Planets tend to have geothermal gradients, whether it's from the cooling of magma, the radioactive decay of long-lived isotopes or tidal heating. As you go deeper, things warm up, and the potential for melting arises.

"Of course, if the oceans get too deep, then as you dive further and further in, higher pressures arise than what we see on Earth, and compaction can lead to new and different forms of solid-phase minerals with the same water composition to form," says German. He also describes this in a way that's simpler to understand: "Some ocean worlds can be ice sandwiches."

Ocean worlds

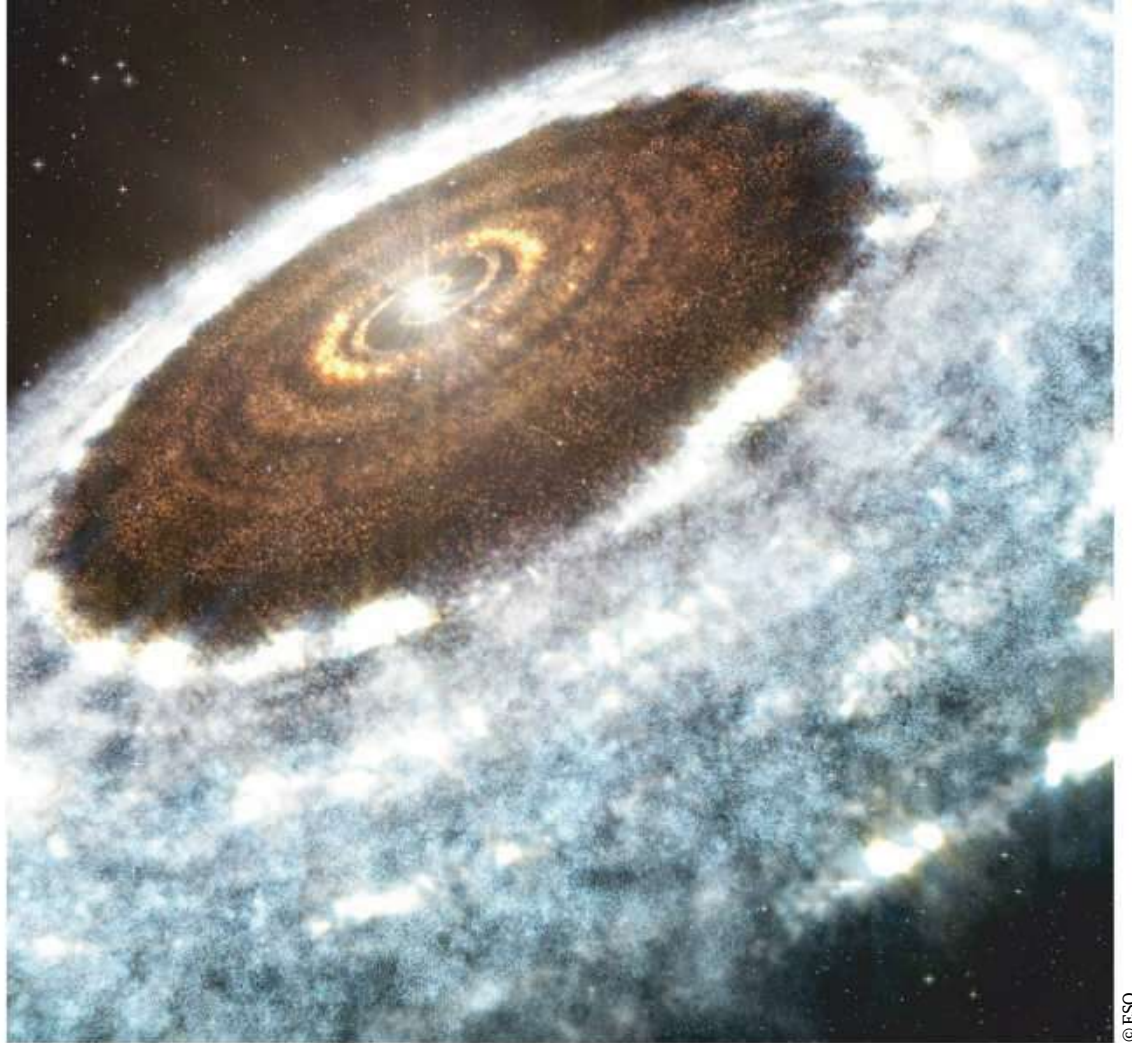
Tidal heating is a term frequently mentioned when talking about ocean worlds, but more specifically the ocean moons that orbit larger planets. The ocean moons beyond the asteroid belt include three of Jupiter's four Galilean moons - Ganymede, Callisto and Europa - as well as Saturn's moons Enceladus, Titan and Mimas and Neptune's moon Triton. The fact that they are all gravitationally bound to enormous planetary bodies means that there is consequently a gravitational sloshing effect in the moons' cores.

This sloshing effect creates heat in the form of friction within the core, which in turn heats up the outer layers. Tidal heating, when combined with radiogenic heating from radioactive decay, melts the water ice accumulated from the moons' formation beyond the ice line and creates interior oceans. When you see one of these moons and acknowledge its icy surface, remember that there is an enormous quantity of subsurface liquid water lying beneath, which astrobiologists are working incredibly hard to try and investigate.

"Ocean worlds are important to study because we can test an important hypothesis in science: biology," explains Dr Morgan Cable, a research scientist for the astrobiology and ocean worlds group at NASA's Jet Propulsion Laboratory (JPL) in Pasadena, California. "We already know that the rules of physics - the speed of light, the theory of general relativity and so on - seem to apply everywhere in the observable universe. The same is true for the rules of chemistry; those also seem to apply everywhere. But we haven't tested this for biology yet. If you have an environment with habitable conditions and you wait long enough, will life emerge?"

Right: This artist's impression shows the 'ice line' around the protostar V883 Orionis

Below: Cassini's dive through the plumes of Enceladus was a monumental occasion in terms of ocean world research



© ESO

On 15 September 2018, NASA's Cassini mission came to an end. During its 13 years at Saturn it returned breathtaking images and invaluable data, not just about the ringed planet, but its moons too. The data returned about Enceladus was key in revitalising public attention towards ocean world research, which had been growing over the last few decades. A notable event which strengthened this shift was when the spacecraft flew through a plume of material erupting from the icy surface of Enceladus on 28 October 2015. With its instruments turned on and ready to go, Cassini dove head first into the plume, and the data taken from this encounter led to remarkable discoveries about

Enceladus' interior. The most important was that within this world, 25-times smaller than Earth, lies the three main ingredients for life: liquid water, an energy source for metabolism and a tantalising selection of chemical ingredients such as carbon, nitrogen, oxygen, phosphorus and sulphur.

With this discovery, astrobiologists made an extremely compelling case that future exploration missions should look to visit more ocean worlds in the outer Solar System. This was once again strengthened when astrobiologists found something very interesting in the data collected by NASA's Dawn mission, which was operational at the dwarf planet Ceres between 2015 and 2018.



© NASA/JPL-Caltech

OCEAN WORLDS OF THE SOLAR SYSTEM

These bodies host their own oceans - which could be teeming with life - and they lie right on Earth's doorstep

EARTH

Size: One Earth radius
Distance from the Sun: 1 AU
Type of ocean: Active



CERES

Size: 0.08 Earth radii
Distance from the Sun: 2.8 AU
Type of ocean: Mature



GANYMEDE

Size: 0.4 Earth radii
Distance from the Sun: 5.2 AU
Type of ocean: Trapped



EUROPA

Size: 0.24 Earth radii
Distance from the Sun: 5.2 AU
Type of ocean: Possibly active



CALLISTO

Size: 0.38 Earth radii
Distance from the Sun: 5.2 AU
Type of ocean: Trapped



ENCELADUS

Size: 0.04 Earth radii
Distance from the Sun: 9.5 AU
Type of ocean: Active



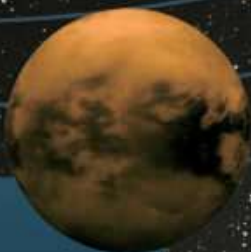
MIMAS

Size: 0.03 Earth radii
Distance from the Sun: 9.5 AU
Type of ocean: Possible



TITAN

Size: 0.4 Earth radii
Distance from the Sun: 9.5 AU
Type of ocean: Trapped



TRITON

Size: 0.2 Earth radii
Distance from the Sun: 30.1 AU
Type of ocean: Possible



PLUTO

Size: 0.18 Earth radii
Distance from the Sun: 39.5 AU
Type of ocean: Possible



TYPES OF OCEAN

Active

Known active ocean with great potential for supporting life.

Mature

The body is ageing and the ocean is in the process of freezing over.

Trapped

Likely has a covering, like ice, over the ocean. Unlikely to support life.

Possible

Shows signs of an ocean, but further investigation is needed to confirm.

Possibly active

There is an ocean, but its potential to support life is currently unknown.

LARGEST OCEANS IN THE SOLAR SYSTEM

Out of all of the known ocean worlds, which one takes home the gold for the largest amount of liquid water present?

Earth



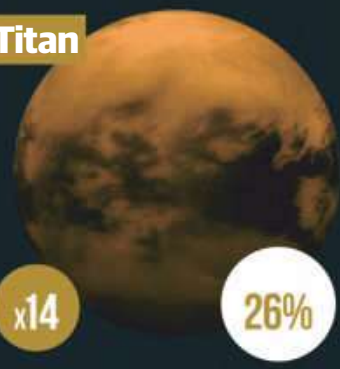
Europa



Callisto



Titan



Ganymede



HOW MUCH WATER IS THERE COMPARED TO EARTH

WHAT PERCENTAGE OF THE WORLD IS LIQUID WATER

Above: Artist's impression of cryovolcanoes erupting on Europa's surface and water under its icy crust

"Measurements from the Dawn mission indicate salts on the surface of Ceres, which can only be there if they are being constantly replenished from underneath. This means Ceres has activity due to brines (salty liquids), making it an 'evolved' or 'mature' ocean world," says Cable. "Based on our current understanding, only a few per cent of Ceres' subsurface ocean is left, so Ceres may serve as an excellent example of what an ocean world without tidal heating looks like at the end stages of its life when the energy runs out."

An honourable mention also goes to NASA's New Horizons mission, which returned the first close-up images of the dwarf planet Pluto from the darkest, most distant region of the Solar System, known as the Kuiper Belt. The images that were transmitted back to Earth from over 5 billion kilometres (3 billion miles) away were truly extraordinary. They revealed cracks on the surface, possible ice volcanoes and an extremely thin atmosphere made up mostly of molecular nitrogen. These are all lines of evidence that could point towards a subsurface ocean that is replenishing the dwarf planet's

atmosphere via the eruption of ice volcanoes or immediate evaporation after escaping through surface cracks.

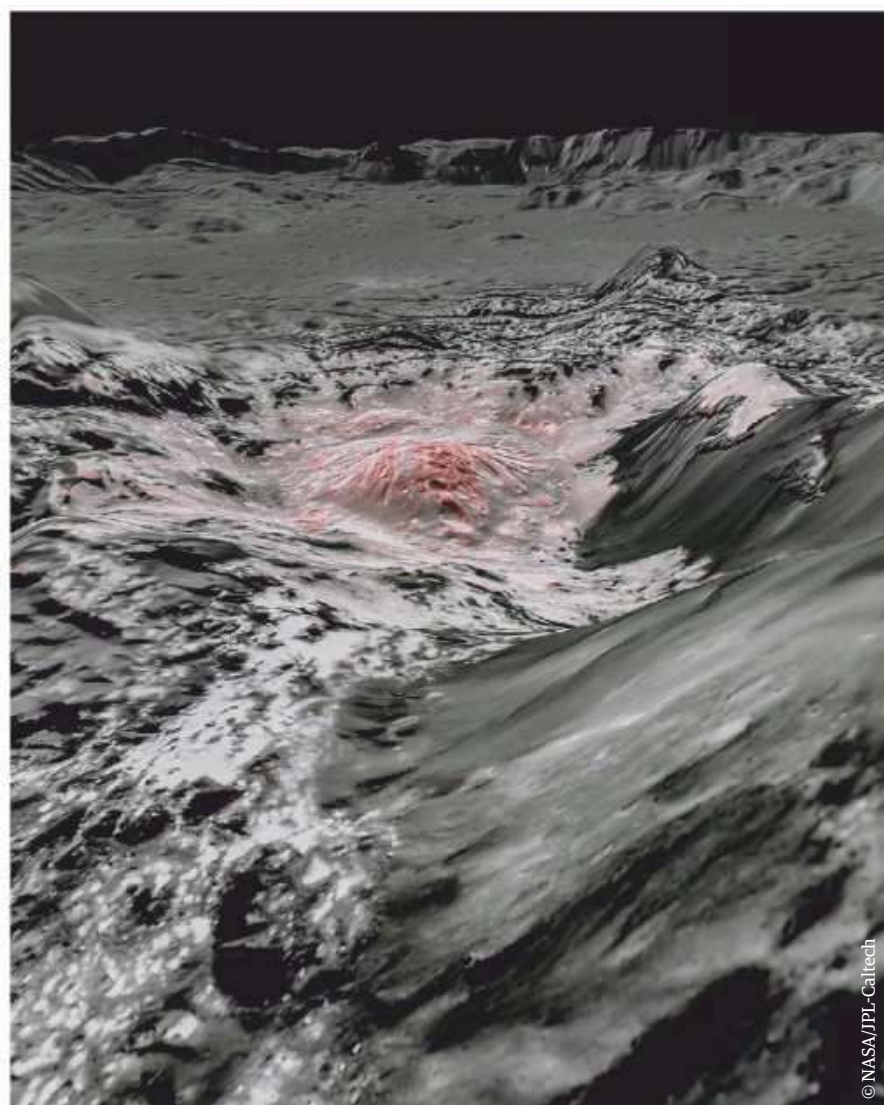
When looking at these ocean worlds and the data collected from their respective exploration missions, it's understandable that astrobiologists can't wait for the next mission to launch and reveal a brand-new host of discoveries. Two missions due to launch within the next decade are NASA's Europa Clipper mission, due to explore Jupiter's moon Europa sometime in the 2020s, and the European Space Agency's (ESA) Jupiter ICy moons Explorer (JUICE), due to arrive at Jupiter in 2029.

These two bespoke moon missions aim to provide a thorough reconnaissance of the three watery Galilean moons, and will look to fully characterise their current states and compositions while also informing us about their evolution over the last 4.6 billion years. Europa is roughly 90 per cent the size of Earth's Moon, but holds twice as much water than all of Earth's oceans combined. The astrobiological processes that may exist in this moon could answer the age-old question: is

© Tobias Roetsch



Below:
This false-colour image highlights salty liquids that have recently risen from the subsurface ocean



POTENTIAL OCEAN WORLDS OUTSIDE THE SOLAR SYSTEM

Planets in the TRAPPIST-1 system

The popular TRAPPIST-1 system – with its seven Earth-sized planets – became even more popular in 2017 when astronomers announced that they could be harbouring liquid water. Three of the planets reside in the star's habitable zone, suggesting they would be the most likely objects of interest.

GJ 1214 b

GJ 1214 b is considered a super-Earth: it is 2.7 times Earth's radius. It's thought it could be surrounded in a steamy atmosphere. This potential ocean world was first discovered in 2009, but research has revealed that the exoplanet's density is closer to water as opposed to Earth's rocky density, which is much greater.

Kepler-22b

This exotic exoplanet has been described by NASA as a "super-Earth that could be covered in a super ocean". This remark is based on the fact that this planet, which is 2.4-times larger than Earth, resides in the habitable zone around a star very similar to the Sun. This implies that it could have a similar evolutionary history to Earth.

Kepler-62f

Located 1,207 light years away in the constellation Lyra, Kepler-62f is a planet 40 per cent larger than Earth and sits in the habitable zone of its host star. A 2016 study of Kepler-62f found that there are multiple atmospheric compositions that allow it to stay warm enough to sustain liquid water.

there life elsewhere in the universe? And if Europa doesn't host life, does it at least have a habitable and hospitable environment for it?

"If we can find evidence in the outer Solar System, that would imply a second origin of life here in our corner of the universe," says German. "Occam's razor then suggests that life should be pervasive in every other star system and we're not that special at all."

There are even efforts underway to test how we could explore these subsurface oceans directly. In 2019 a team of engineers from NASA's JPL travelled to Antarctica to test the Buoyant Rover for Under-Ice Exploration (BRUIE), a roving vehicle built with the long-term goal of exploring the subsurface oceans of icy moons.

BRUIE uses a unique combination of buoyancy and wheels with tiny spikes in them to move along the underside of ice sheets. This rover would be able to provide direct measurements of an ocean's water salinity, dissolved oxygen levels, temperature and pressure. Who knows, one day in the future there could be a new documentary series talking

"CERES MAY SERVE AS AN EXCELLENT EXAMPLE OF WHAT AN OCEAN WORLD WITHOUT TIDAL HEATING LOOKS LIKE AT THE END STAGES OF ITS LIFE" MORGAN CABLE

about the oceans of Europa and what ocean life is swimming around in there!

Looking beyond our own Solar System, there are many exciting opportunities for discovering ocean worlds in other stellar systems. Unfortunately these are a little bit harder to detect, but there are still techniques that can be used to infer their existence. "We can identify ocean worlds in extrasolar planetary systems based on their size and inferred density," says Quick. "Low-density, low-mass planets are likely to be ocean worlds."

A simple technique that is commonly used in astronomy when it comes to aiding

THE FUTURE OF OCEAN WORLD EXPLORATION

These robotic explorers could provide vital evidence to answer astrobiology's greatest questions

1 EUROPA CLIPPER

NASA's next mission beyond the orbit of Mars is the Europa Clipper, succeeding the Juno mission currently at Jupiter. The mission is scheduled to launch in the mid-2020s. The spacecraft will carry nine scientific instruments, each built for a specific purpose, and will conduct a full scan of the surface. It will also utilise ice-penetrating equipment in order to characterise Europa's subsurface ocean.

2 JUICE

The European Space Agency has also taken a particular interest in the Galilean moons and looks to visit three of them during its three-and-a-half-year stay. It will arrive at the Jovian system in 2029 and investigate each moon's environment and the relationship between the three. However, particular emphasis will be on Ganymede.

3 BRUIE

Although this mission is unlikely to see extraterrestrial exploration within the current decade, it has already been tested in Earth's best analogue location: Antarctica. The buoyancy and manoeuvrability of the Buoyant Rover for Under-Ice Exploration vehicle represents a unique and feasible method of gaining direct insight into subsurface oceans.

"AN OCEAN WORLD IS ANY PLANET, OR SOMETIMES MOON, THAT HAS AT LEAST TEN TIMES THE AMOUNT OF WATER THAT EARTH DOES"

LYNNAE QUICK

research regarding an exoplanet's potential for accommodating liquid water is calculating if a planet resides in its host star's habitable zone. This is the radius range around a host star where the temperature is perfect for water to exist as a liquid. If the planet orbited any closer the water would evaporate, but if the planet was too far away the water would freeze into ice.

This basic technique is used by astrobiologists when determining if an exoplanet could host liquid water as it's known that Earth resides in the Sun's habitable zone. It's important to remember that this is an extreme simplification and does not take into account things such as a planet's composition, atmosphere, evolution history and so much more.

To make a discovery of this calibre with great confidence and little uncertainty, the techniques that astrobiologists and astronomers use to detect exoplanets and analyse them will need to be improved in order to infer other aspects of a planet's properties - this includes its atmosphere. "Astronomers can further their techniques by improving spectral resolution and sensitivity," says Cable. "This would help us identify possible biosignature molecules in the atmospheres or on the surfaces of exoplanets."

Recent research suggests that the Milky Way could be littered with ocean worlds. A study led by Quick suggests that out of the 53 exoplanets surveyed, at least 30 of them could be ocean

worlds, as they fit the assumed parameters. This is based on restricted knowledge, however, as current technologies and techniques allow astronomers to definitively measure an exoplanet's size, mass and distance from the host star, which can only imply a planet's surface temperature. "If we see that a planet's density is lower than Earth's, that's an indication that there might be more water there and not as much rock and iron," Quick says. "But if a planet's surface temperature is less than 32 degrees Fahrenheit [0 degrees Celsius], where water is frozen, then we have an icy ocean world, and the densities for those planets are even lower."

With the number of known exoplanets currently over 4,000, Quick's results could be extrapolated, suggesting that there are thousands of ocean worlds dotted across the Milky Way. Quick also makes the point that there could be other signature signals of ocean worlds that are currently unknown, and that upcoming missions, for example the Europa Clipper mission, will identify these signals.

This could then be applied to exoplanet research in order to identify even more ocean worlds. This could provide greater reliability and accuracy about whether an exoplanet is an ocean world, since it provides something more meaningful than just inferring information based on the planet's size, mass and density.

Even the recent news regarding Ceres likely being a more mature ocean world could give astronomers new signs and biosignatures to look out for when investigating exoplanets. The study of ocean worlds, both within our Solar System and elsewhere in the cosmos, is certainly one to keep a keen eye on. Through upcoming missions astrobiologists will become even more equipped with highly precise data that could answer one of the most profound questions there is, finally revealing if life on Earth is special or not.

Above: Kepler-62f has the potential to be an ocean world, but it is far from confirmed as of yet

Left: Jupiter next to its four Galilean moons. From top to bottom: Io, Europa, Ganymede and Callisto



© NASA/JPL-Caltech



© NASA/JPL



Lee Cavendish
Staff Writer

Lee holds a degree in observational astronomy, which has given him the knowledge to discuss the latest complexities of the universe.

1 Satellites

The diameter of the Sun is 100-times greater than Earth's, so we'd need to evenly spread out solar-powered satellites to gather energy for transfer to Earth.

6 Energy

Our Sun radiates over 500,000-times more energy every second than the current annual energy consumption of humans on Earth. A Dyson sphere would make use of that energy instead of letting it 'go to waste'.

2

2 Mass

If the satellites were fairly small, the amount of material needed to build them would reduce drastically, therefore making the proposal more feasible.

3

3 Sails

The satellites would be kept in position around the star by virtue of large lightsails, which would use the radiation pressure of the star to counteract the force of gravity.

4

7

DYSON SPHERE

5

Could an advanced civilisation harness the power of stars to sustain their energy needs?

6

First proposed by physicist Freeman Dyson in 1960, a Dyson sphere is a hypothetical swarm of satellites that would surround a star in order to harness its energy. Although more commonly known as a Dyson swarm, some people have discussed the possibility that rather than a swarm of satellites, a star could be encased in a solid sphere by a future civilisation - but this is an idea that Dyson himself was keen to stray away from. Indeed, for a planetary system like our own, such a structure would likely require every object in the Solar System other than the Sun to be dismantled and rebuilt into a giant sphere owing to the huge size of the Sun.

Dyson's initial proposal was suggested as a way that a future civilisation could satiate their vast energy needs. As the energy requirements of a civilisation increase, they may require an ever-growing amount of energy, a crisis perhaps solved only by harnessing the power of stars.

This carries further connotations that there could be advanced races elsewhere in the universe that have built such structures. Dyson postulated that these would radiate a large amount of infrared radiation, noticeable even to us here on Earth.

The idea has gained enough ground that the SETI Institute in California has been on the lookout for Dyson spheres, while Fermilab near Chicago has carried out its own analysis of observations from outside the Solar System to ascertain the likelihood of the existence of Dyson spheres. Aside from finding four candidates that were "amusing but still ambiguous and

questionable," though, nothing too promising has been found.

While fun to imagine, the logistics of a Dyson sphere are also quite far-fetched. Taking the solid shell idea, a structure would be thin - at perhaps just a few tens or hundreds of metres thick - with its membrane covered in solar panels, but it would still be many times more massive than Earth. Placed around a star, it would have little chance of keeping its structural integrity; if made to rotate so as to keep it in 'orbit' around the star, the areas around its artificial equator would be stable, but at the poles, where there is no rotation, the structure would succumb to the forces of gravity and collapse.

This is why Dyson favours the swarm idea. With this, many thousands of solar-energy-gathering satellites would be placed around the star. They would then beam their energy to a central hub to be utilised by a civilisation. Using separate satellites, all in orbit around the star, the structure would remain intact and huge amounts of energy could be transferred from the star.

While this particular structure might seem impractical, something on a smaller scale could feasibly do a similar job. For example, some theories suggest that a large solar-gathering spacecraft placed between Earth and the Moon would be able to absorb huge amounts of power that could be beamed to our planet.

Known as space-based solar power (SBSP), this is something that science-fiction writers have favoured, and is a much more promising technology than an entire Dyson sphere. However, perhaps many thousands of years in the future when we become interstellar explorers, it may be necessary to find huge resources of energy, and as far as we know there's nothing better than an entire star.

8 Transfer

Some form of wireless energy transfer, such as the use of microwaves, would be used to beam energy from the Sun to Earth.

8

4 Poles

A 'swarm' of orbiting satellites is preferred to a solid sphere, as the latter would likely lose structural integrity at the poles where there is no rotation.

7 Infrared

Such a construction would likely emit large amounts of infrared radiation, perhaps enough to be detected by a species in a separate planetary system.

5 Alien civilisations

Searching for the signature of a star being harnessed for energy in this way could be our best bet for finding intelligent extraterrestrial life.

INTERVIEW BIO

**Professor
James Peebles**

Peebles is the Albert Einstein professor of science, emeritus, at Princeton University, New Jersey. His contributions to science, astrophysics and cosmology since the 1960s have shaped how we think about the entire universe. This effort led to him winning the 2019 Nobel Prize in Physics, sharing it with fellow professors Michel Mayor and Didier Queloz.

© Getty

NOBEL PRIZE WINNER JAMES PEEBLES

“WHY I REINVENTED SPACE AND TIME”

All About Space chats to the 2019 Nobel laureate in physics about his involvement in many groundbreaking discoveries and how our theories have evolved since he first began studying the universe

Interviewed by Lee Cavendish

It takes a brilliant mind to imagine what the universe was like from its inception and try and model it over roughly 14 billion years. How have you been able to attempt this and be so confident in your results?

You should bear in mind that people were talking about this expansion of the universe from what used to be called a ‘primaeval atom’ since the 1930s. There was nothing new in this concept. It was not imagination so much; it was just inertia. People had no other ideas. What’s happened since then is an accumulation of an enormous amount of experimental evidence.

The Big Bang theory is widely accepted now, even by the general public. How was the theory received when you first came into the field of cosmology? Was it as widely accepted then as it is today?

Oh, no. It was widely known in the physics community. I think you could say it was not taken very seriously. It was doubted and not believed. Instead it was an idea that had very little basis in hard empirical evidence.

What can you tell us about your part in the discovery of the cosmic microwave background?

Let’s just consider the situation after World War II; there was an immense release of energy in science

and technology. It gave us automobiles and it gave us particle accelerators. I guess it was natural that scientists turned to cosmology. The idea of an early, dense universe expanding into the present state was around, as I said, since the late 1920s and early 1930s.

People started taking up the idea, in particular Bob [Robert] Dicke, [former Albert Einstein professor in science at Princeton University]. In the Soviet Union, Yakov Zeldovich became interested independently. In the UK Fred Hoyle, Thomas Gold and Hermann Bondi became interested. The former Ukrainian, George Gamow, who had immigrated to the United States, also became very interested in the subject.

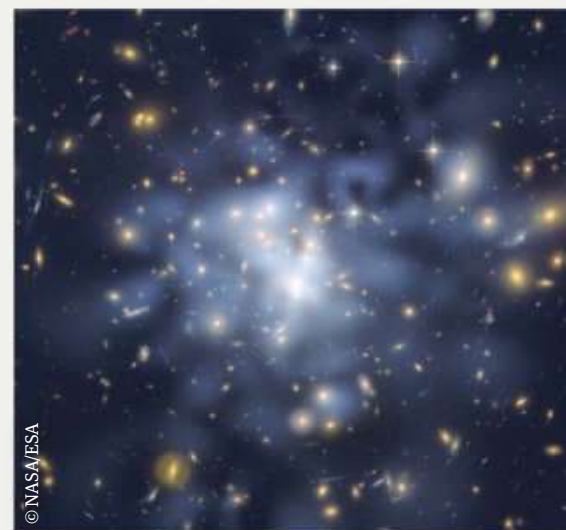
These people, each brilliant physicists, became interested in this independently. Gamow had proposed earlier, in 1948, the notion of a hot Big Bang, but with that came a distinct lack of interest in details. He put together many of the important ideas about a hot Big Bang. In particular he recognised that a hot Big Bang would have radiation in it. That radiation would be smoothly distributed. It would have a thermal spectrum. As the universe expanded, radiation would cool, but it would keep its thermal spectrum.

Meanwhile, Fred Hoyle in the UK became aware of the fact that astronomers were finding evidence of a remarkably high helium abundance, and the

problem became where that helium came from. Although Hoyle loathed the hot Big Bang theory – remember he was a supporter of the steady state theory – he, as a good scientist, published a paper with Roger Tayler which had the title, *The Mystery of the Cosmic Helium Abundance*. He pointed out that this helium could have come from Gamow’s hot Big Bang.

Meanwhile, here at Princeton, Bob Dicke had decided, for his own reasons, that a hot Big Bang might be interesting. He advised two of the young postdocs in his research group to build a radiometer – of the kind he invented during World War II – to see if this radiation might be present.

Right: Modern astronomers have been able to indirectly measure dark matter distribution within galaxy clusters



Interview Professor James Peebles

He then turned to me and said, "Why don't you think of the theoretical implication?" Peter Roll, one of his postdoc students, went on into education, whereas David Wilkinson and I spent the rest of our careers following up Dicke's idea.

Meanwhile, Bell Laboratories in northern New Jersey was developing the technology for microwave communications. The engineers at Bell Laboratories received an anomaly. Their receivers were detecting more radiation than what they could account for.

By 1964 two of the young people there - Arno Penzias and Robert Wilson - were struggling to discover what might be the source of this radiation. They're greatly accredited for refusing to give up and for complaining about it until finally the word got back to Princeton and everything came together.

So Penzias and Wilson just happened to stumble across it, and with your help managed to identify it?

That's right. They had it. They didn't know what it was. We were looking for it, and when we got together, well, there was radiation noise in the microwave receivers and there was the helium that Fred Hoyle knew about. You see, no one person can be credited with this, besides maybe Gamow. It was the work of many people coming together... almost stumbling together.

Would it be correct to say that this was the start of physical cosmology and applying known physics to the large-scale structure of the universe?

Yes, you could say that. People were applying physics earlier, but it was pretty schematic. The

important thing about this radiation is that it was there. You could measure it, you could see how it was distributed, you could also measure its spectrum and you could, of course, knowing that there's a temperature, do a lot of physics that was meaningful. We can't say that the new physical applications started then, but they suddenly became a lot richer.

It has been stated that there is just five per cent visible baryonic matter in the entire universe.

How do you get people to wrap their heads around that?

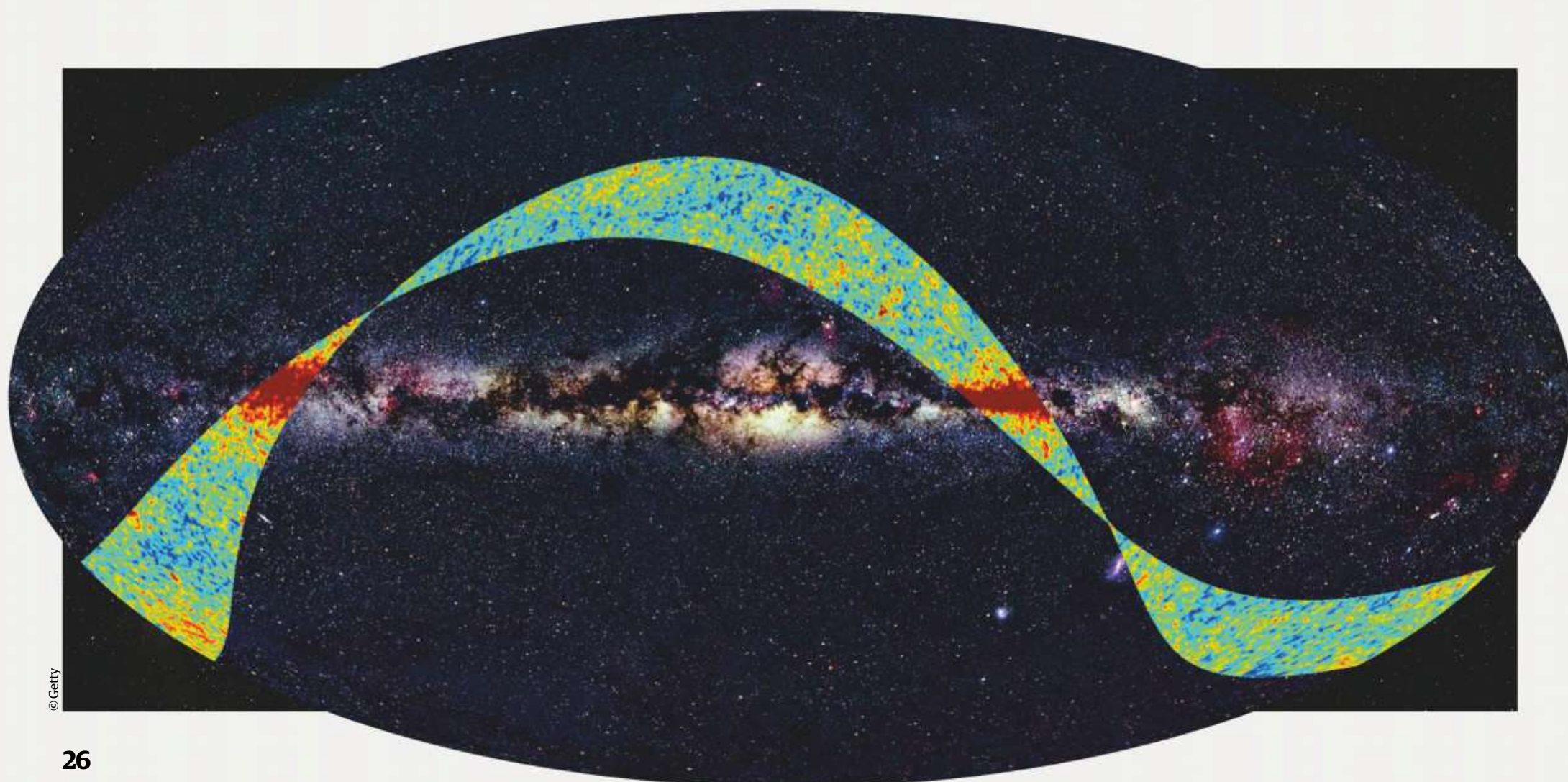
I could explain why I introduced that non-baryonic matter - the matter that you can't touch. It's all because the radiation is very smoothly distributed. The matter we see, galaxies and so forth, is very clumpy. As the universe expanded and cooled, how could matter gather into these great clumps of galaxies and leave the radiation so smooth? The thing is that as matter gathers together to make galaxies, you would drag the radiation with it and mess it up.

The postulate I introduced in the early 1980s is that most matter is not the sort of matter you and I are made of, but rather it doesn't interact with matter and radiation. And so the radiation could slip through this non-baryonic dark matter. It was, at the time, an ad-hoc guess as to what allowed the radiation to be so remarkably smooth. At the time I didn't argue very forcefully for it, because it was rather a demonstration of what could have happened. It was that easy in the 1980s and early 1990s because I could think of other ways to account for this phenomenon. This was just the simplest. People were very attracted to the idea because it's simple.



Left: Galaxies appear very clumpy throughout the universe and do not explain the smoothly distributed radiation of the CMB

Below: Our eyes are only sensitive to visible light and cannot reveal the CMB, which is shown here as the false-coloured strip



There are some fantastic missions with cosmological objectives coming to fruition in the near future. Do you think these missions will play an important role in providing valuable observations for theories?

I'm really hoping so. There are a whole series of missions I'm looking forward to, and we shouldn't forget the missions already in progress. Laboratory detection of dark matter has been going on since the 1980s. Year after year [there has been] improved sensitivity, bigger detectors, better insulation against cosmic rays.

At any time we might hear the breathless announcement: dark matter has been detected. If you hear that, you should be a little careful because it's very likely, I think, that the dark matter is more complicated. Perhaps it will be a laboratory detection of a sub-dominant part of the dark matter. We'll have to wait and see. Anyway, that will be exciting when it happens. Of course, there's no guarantee it will.

The precise measurements of the radiation distribution will show us, among other things, whether we've assumed the right initial conditions. You have to bear in mind that this theory is not at all complete. It has a set of assumptions, and among others is the initial conditions, which I assumed were the simplest of all possibilities. They work pretty well. There have been adjustments already and maybe more adjustments are in store.

Regarding your recent Nobel Prize win, how did you receive the news that you'd just won?

A telephone call at a convenient time in Stockholm, but five o'clock in the morning here in Princeton.

When we spoke to fellow laureates Michel Mayor and Didier Queloz about your shared Nobel Prize win earlier in the year, they spoke about how their field of research will benefit from this acknowledgement, and they hope it will inspire future researchers. Is this something that resonates with you?

That certainly does. It's a little hard to credit how influential the Nobel Prize is. There are other major prizes - major in the sense that there is big money for a lot of good work - but they have nowhere near the visibility, or the weight, of the Nobel Prize. I have suddenly become this iconic figure, which makes me a little nervous. I'm still the same person I was before. But yes, the entire world is so impressed by this.

Do you think that with this acknowledgement, astronomy, and cosmology specifically, will gain fresh researchers?

I think there's a mixed situation. On the one hand, the Nobel Prize carries great weight, not only in the general public, but upon my colleagues. Suddenly they're more impressed. That's great. But they're



Above: In 2019 UK scientists greatly improved their xenon detectors, which were then lowered underground for dark matter detection

Right: Peebles' work since the 1960s has helped define cosmology and understand the Big Bang

© Tobias Roetsch



"I HAVE SUDDENLY BECOME THIS ICONIC FIGURE, WHICH MAKES ME A LITTLE NERVOUS. I'M STILL THE SAME PERSON I WAS BEFORE"

doing work they would have done anyway, and I don't think any practising scientist has been influenced by the Nobel Prize to do something different from what they're doing now. And I don't know; maybe some will be inspired to follow in my footsteps. The problem I caution them is that my footsteps have already been taken. You can't go back and do it again in the same way. You're going to have to follow your own path. It has to be different from mine.

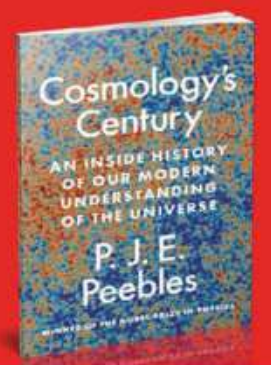
Also, I should make an important point. Winning such a prize depends on a lot of things, a lot of hard work, but also a lot of eventualities that line up in just such a way as to make the case for the Nobel Prize clear to the committee. That means that a young person starting out in physical science should not judge his or her career by prizes and awards. They have to be capricious, because so many things have to line up to make it work. Judge yourself by your accomplishments, by your record in the field, but not by prizes and awards.

How does it feel for your name to be in the same sort of history book, as a Nobel Prize laureate, as such names as Albert Einstein, Niels Bohr and Richard Feynman?

[Laughs]. I think I was fortunate in the fact that I reached a good age. I was 85 when I received the prize. I knew what I'd done and I felt comfortable with it and I feel - without boasting - the Nobel committee made a good choice. But I'm no longer much affected by it, if you know what I mean. Life is the same for me, apart from the uncomfortable obligation to talk more to people. Normally we live a very quiet life and I enjoy it. I continue to work on research at a modest level, but now I've become a spokesperson, which I'd never planned to be.

Cosmology's Century: An Inside History of Our Modern Understanding of the Universe

James Peebles details the journey through the last 100 years of astronomy and cosmology that have left us pondering the universe's biggest questions. Peebles offers a unique insight and perspective into how the cosmos has evolved over the last 13.8 billion years and how our theories are still incomplete.



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STRANGEST MOONS IN THE SOLAR SYSTEM

Some of the most fascinating worlds in our cosmic neighbourhood are not planets, but the moons that orbit around them

All but two of our Solar System's planets have satellites of one sort or another. Earth's own Moon, a beautiful but stark, dead world shaped by ancient volcanoes and countless impact craters, is undoubtedly the most familiar, but it's far from being the most interesting.

Each of the outer Solar System's giant planets is accompanied by a large retinue of satellites, many of which formed at the same time and from the same ice-rich material as the planets that host them. Although far from the Sun and starved of solar heat and light, they nevertheless show as much variety as the planets themselves.

Here **All About Space** takes a trip to visit some of the strangest and most exciting of these astonishing worlds. Some, such as Jupiter's Callisto and Saturn's Mimas, have been frozen solid for billions of years but bear extraordinary scars from exposure to bombardment from

space. Others, such as Saturn's shepherd moons Pan and Atlas and Neptune's lonely Nereid, have been affected throughout their history by interactions with their neighbours.

Most excitingly, some of these exotic worlds have been heated by powerful tidal forces from their parent planets, triggering phases of violent activity like those which shaped Miranda, Uranus' Frankenstein moon. In some cases these forces are still at work today, creating fascinating bodies such as Jupiter's tortured Io and Saturn's icy Enceladus, whose placid exterior may even hide the greatest secret in the Solar System: extraterrestrial life itself.



Giles Sparrow

Space science writer

The author of over 20 books on popular science, Giles holds a degree in astronomy and is an editor specialising in science and technology.

ENCELADUS THE RING BEARER

Mass: 1.1×10^{20} kg (2.4 x 10²⁰lbs) **Diameter:** 504km (313 miles) **Parent planet:** Saturn **Discovered:** 1789, William Herschel

Since NASA's Cassini probe arrived at Saturn in 2004, the ringed planet's small inner satellite, Enceladus, has become one of the most intensely studied and debated worlds in the entire Solar System. It owes its new-found fame to the discovery of huge plumes of water ice erupting into space along fissures in its southern hemisphere - a sure sign of liquid water lurking just beneath the moon's thin, icy crust.

The strange activity of Enceladus was suspected before Cassini's arrival thanks to earlier images that showed the moon has an unusually bright surface and craters that look like they are blanketed in snow. Nevertheless, the discovery of the ice plumes - initially made when Cassini flew straight through one - was a spectacular confirmation that Enceladus is an active world.

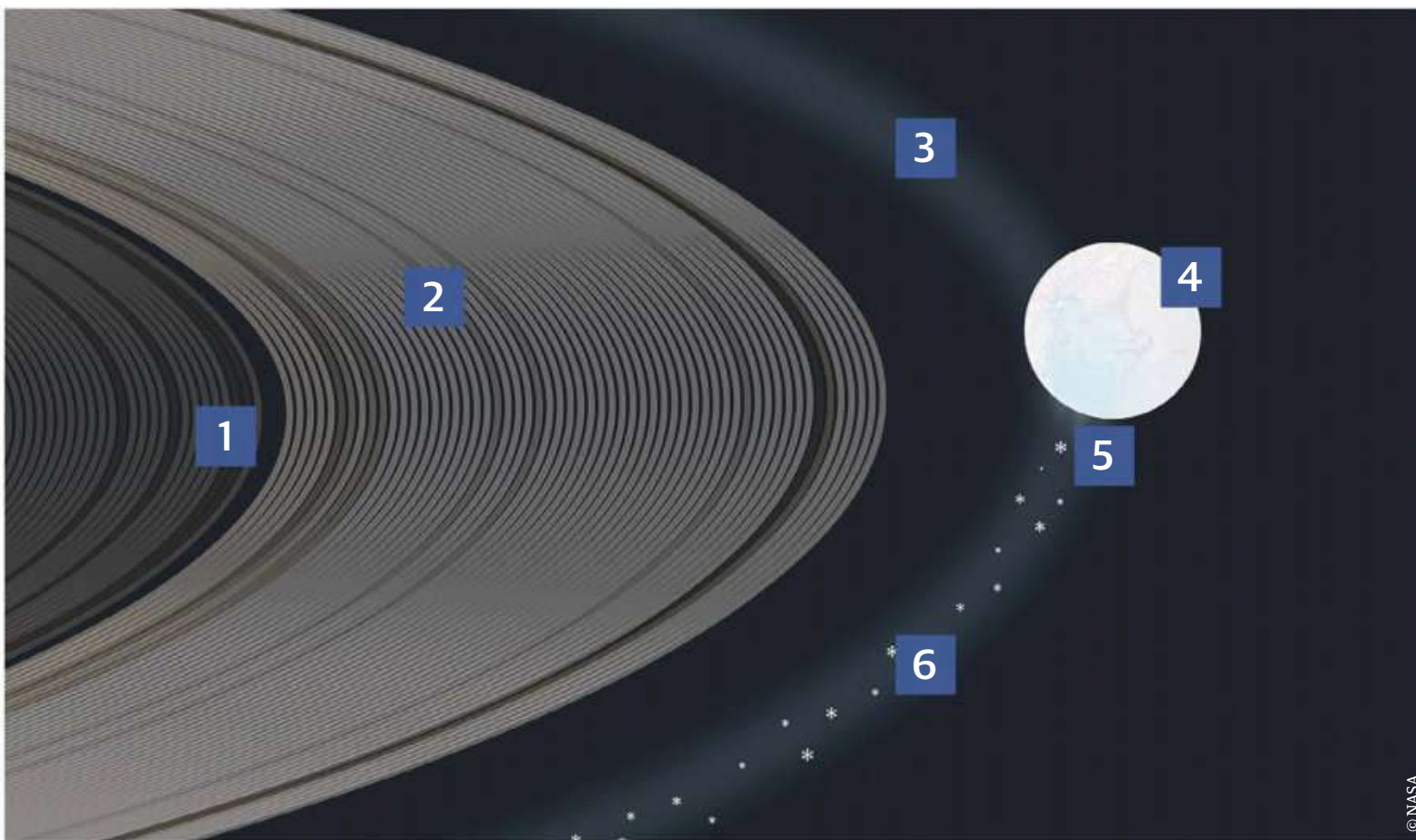
With a diameter of 504 kilometres (313 miles) and a rock/ice composition, Enceladus should



have frozen solid billions of years ago, like many of its neighbours in the Saturnian system. But tidal forces caused by a tug of war between Saturn and a larger moon, Dione, keep the moon's interior warm and active, making it a prime target in the hunt for life in the Solar System.

While much of the water ice falls back to cover the surface, a substantial amount escapes from the weak gravity and enters orbit around Saturn. Here it spreads out to form the doughnut-shaped E Ring - the outermost and sparsest of Saturn's major rings.

“THE DISCOVERY OF THE ICE PLUMES WAS A SPECTACULAR CONFIRMATION THAT ENCELADUS IS AN ACTIVE WORLD”



1 Inner rings

The broad Cassini Division separates the A Ring from the inner B, C and D Rings.

2 A Ring

Saturn's brightest ring is the A Ring, divided by the narrow Encke Gap. The ultra-fine F Ring runs around its outer edge.

3 E Ring

The E Ring is a broad, largely transparent ring of scattered icy particles.

4 Orbit of Enceladus

Enceladus' orbit around Saturn coincides with the densest part of the E Ring.

5 Geyser faults

Tidal forces create an ocean that erupts as icy plumes along weak fault lines in the southern hemisphere.

6 Fragmented material

Small ice fragments trailing behind Enceladus are ground down into ever-finer particles as they orbit Saturn.

CALLISTO THE MOST CRATERED WORLD



Mass:

1.1×10^{23} kg (2.4 x 10²³lbs)

Diameter:

4,821km (2,996 miles)

Parent planet: Jupiter

Discovered: 1610,

Galileo Galilei

The outermost of Jupiter's Galilean moons, Callisto is the third-largest moon in the Solar System and is only slightly smaller than Mercury. Its main claim to fame is the title of most heavily cratered object in the Solar System; its dark surface is covered in craters down to the limit of visibility, the deepest of which have exposed fresh ice from beneath and scattered bright 'ejecta' debris across the surface.

Callisto owes its cratered surface to its location in the Jupiter system - the giant planet's gravity exerts a powerful influence, disrupting the orbits of passing comets and often pulling them to their doom, most spectacularly demonstrated in the 1994 impact of Comet Shoemaker-Levy 9.

Jupiter's larger moons are directly in the firing line and end up soaking up more than their fair share of impacts, but Callisto's inner neighbours - influenced by greater tidal forces - have all experienced geological processes that wiped away most of their ancient craters. Callisto's surface, however, has remained essentially unchanged for more than 4.5 billion years, developing its dense landscape of overlapping craters across aeons.

DACTYL THE ASTEROID MOON

Mass: Unknown **Diameter:** 1.4km (0.87 miles) **Parent planet:** 243 Ida **Discovered:** 1993, Galileo space probe

243 Ida's moon is tiny, just 1.6 kilometres (0.99 miles) on its longest axis. Thanks to the larger asteroid's weak gravity, Dactyl is unlikely to be an object captured into orbit, but the alternative - that Ida and Dactyl formed alongside each other - raises as many questions as it answers.

Ida is a major member of the Koronis family of over 300 asteroids, all of which share similar orbits. The family is thought to have formed 1 or 2 billion years ago during an asteroid collision. Dactyl could be a smaller fragment of debris from the collision that ended up in orbit around Ida, but there is a problem - computer models suggest Dactyl would almost certainly be destroyed by an impact from another asteroid. So how can it be over a billion years old?

One theory is that the Koronis family is younger than it appears, and Ida's heavy cratering is due to a storm of impacts triggered in the original break-up. Another theory is that Dactyl has suffered a disrupting impact, but has pulled itself back together in its orbit - which might explain its surprisingly spherical shape.

1 Direction of orbit

Dactyl orbits in the same direction as Ida's rotation.

Dactyl's orbit is still unknown - Galileo approached the asteroid in Dactyl's orbital plane, so its images provided limited data



2 Encounter distance

Dactyl was about 90 kilometres (56 miles) from Ida during Galileo's flyby.

3 Close approach

Computer models show that Dactyl can come no closer to Ida than 65 kilometres (40 miles) for its orbit to remain stable.

4 Range of possibilities

These tracks show a range of potential orbits that would fit Galileo's observations.



© NASA/JPL-Caltech

IAPETUS THE WALNUT

Mass: 1.8×10^{21} kg (4.0 x 10²¹lbs) **Diameter:** 1,469km (913 miles) **Parent planet:** Saturn **Discovered:** 1671, Giovanni Cassini

Iapetus has two distinct claims to a place in any list of weird satellites. The first became obvious when it was discovered in 1671 - it is much dimmer when seen on one side of its orbit compared to the other. Its leading hemisphere - the half that faces 'forwards' as it orbits Saturn - is dark brown, while its trailing hemisphere is light grey. One early theory to explain the colour difference was that the leading side is covered in dust generated by tiny meteorite impacts on small outer moons, which spirals towards Saturn.

However, images from Cassini reveal a more complex story. Most of the dark material seems to come from within Iapetus, left behind as dark 'lag' when dust-laden ice from the moon's surface sublimates - turns from solid to vapour. The process was likely started by dust from the outer moons accumulating on the leading hemisphere, but once it began, the tendency of the dark surface to absorb heat has caused a runaway sublimation effect.

Iapetus is also ringed by a mountainous equatorial ridge that is 13 kilometres (eight miles) high and 20 kilometres (12 miles) wide, giving the moon its distinctive walnut shape. The origins of this ridge are puzzling - some theories suggest it is a 'fossil' from a time when Iapetus span much faster and bulged out at the equator, while others think it could be debris from a ring system that once encircled the moon and collapsed onto its

NEREID NEPTUNE'S BOOMERANG

Mass: 3.1×10^{19} kg (6.8 x 10¹⁹lbs) **Diameter:** 340km (211 miles) **Parent planet:** Neptune **Discovered:** 1949, Gerard Kuiper

Nereid was the second moon found to orbit Neptune, and its claim to fame arises from its extreme orbit. Nereid's distance from Neptune ranges between 1.4 million and 9.7 million kilometres (870,000 and 6 million miles). This orbit is usually typical of captured satellites - asteroids and comets swept up into highly eccentric orbits by the gravity of the giant outer planets - but Nereid's unusually large size suggests a rather more interesting story.

Evidence from Voyager 2's 1989 flyby suggests that Triton was captured into orbit from the nearby Kuiper Belt. Triton would have disrupted the orbits of Neptune's original moons, ejecting many of them. But many astronomers believe Nereid could be a survivor, clinging on at the edge of Neptune's gravitational reach.



Source: Wikipedia Commons © The Singing Badger

IO THE COLD INFERNO

Mass: 8.93×10^{22} kg (1.97×10^{23} lbs) **Diameter:** 3,643 km (2,264 miles) **Parent planet:** Jupiter **Discovered:** 1610, Galileo Galilei

Io is the innermost of the four giant Galilean moons that orbit the Solar System's largest planet, Jupiter. But while the outer three are - at least outwardly - placid, frozen worlds of rock and ice, Io's landscape is a virulent mix of yellows, reds and browns, full of bizarre and ever-changing mineral formations created by sulphur that spills onto its surface in many forms. Io is the most volcanic world in the Solar System. Io's strange surface was first observed during the Pioneer space probe flybys of the early 1970s, but its volcanic nature was only predicted weeks before the arrival of the Voyager 1 mission in 1979.

The moon is caught in a gravitational tug of war between its outer neighbours and Jupiter itself, and this prevents its orbit from settling into a perfect circle. Small changes in Io's distance from Jupiter - less than 0.5 per cent variation in its orbit - create huge tidal forces that pummel the moon's interior in all directions. Rocks grinding past one another heat up due to friction, keeping the moon's core molten and creating huge subsurface reservoirs of magma.

While the majority of Io's rocks are silicates similar to those on Earth, these have relatively high melting points, and so are mostly molten in a hot magma ocean that lies tens of kilometres below the surface - most of Io's surface activity, in contrast, involves sulphur-rich rocks that can remain molten at lower temperatures.

Together these two forms of volcanism have long since driven away any icy material that Io originally had, leaving a world that is arid and iceless despite an average surface temperature of -160 degrees Celsius (-256 degrees Fahrenheit).



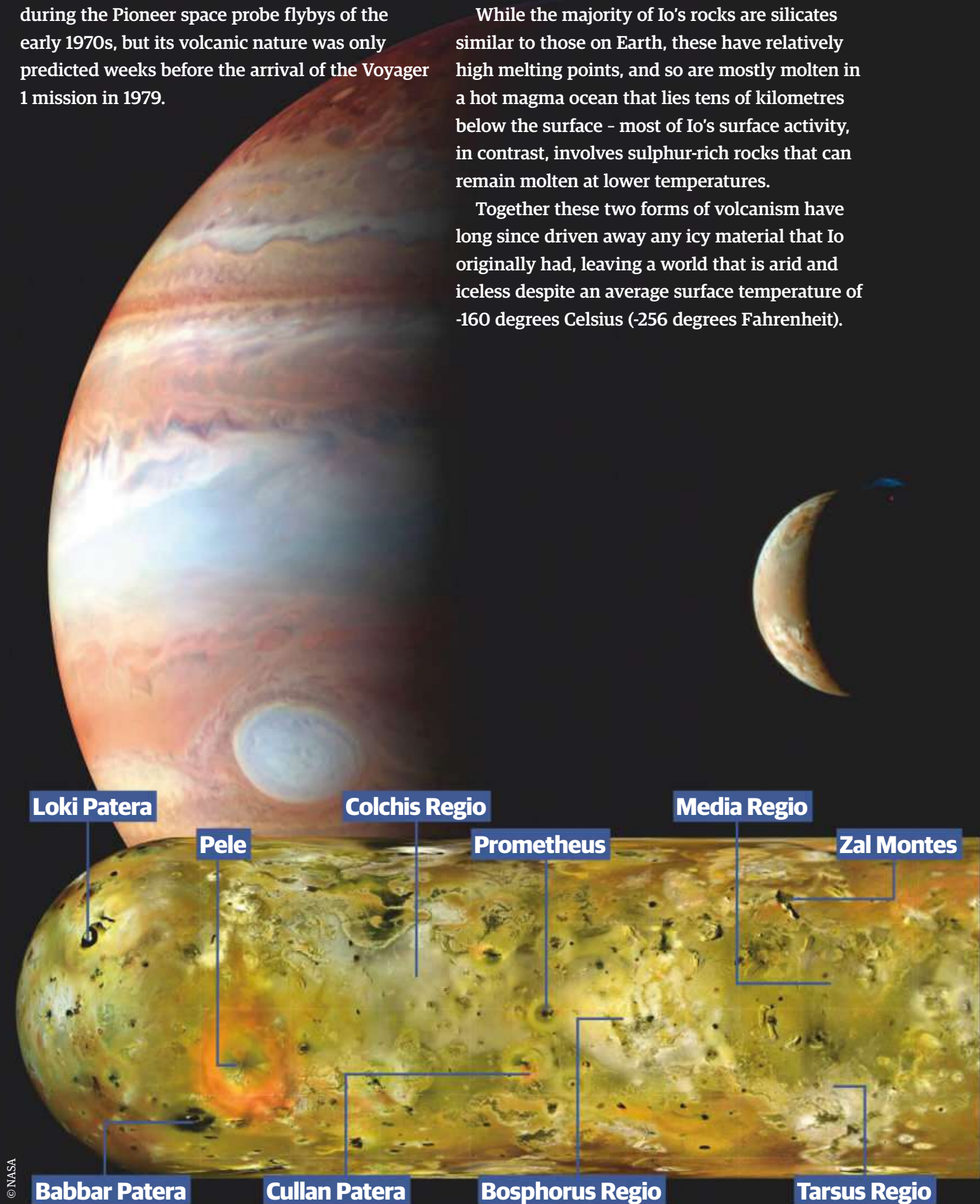
HYPERION THE SPONGY SATELLITE

Mass:
 5.6×10^{18} kg (1.2×10^{19} lbs)
Diameter:
270 km (168 miles)
Parent planet: Saturn
Discovered: 1848, William Bond, George Bond and William Lassell

Hyperion is the strangest-looking satellite in the Solar System, its surface resembling a sponge or coral with deep, dark pits rimmed by razor-sharp ridges of brighter rock and ice. But that's not the only thing that's strange about Hyperion: it was the first non-spherical moon to be discovered and has a distinctly eccentric orbit.

Rather than matching its rotation to its orbital period, it spins in a chaotic pattern, with its axis of rotation wobbling unpredictably. Like all moons in the outer Solar System, it's mostly made of water ice, but its surface is unusually dark. When Cassini flew past it measured its density to be 55 per cent that of water - its interior is mostly empty space.

One popular theory to explain these weird features is that Hyperion is the surviving remnant of a larger satellite that once orbited between Titan and Iapetus, and which was largely destroyed by a collision with a large comet. Material that survived in a stable orbit then came together again to create Hyperion as we know it.



Strange moons

1 Weak sunlight

Titan's distance from the Sun and its thick atmosphere mean that the surface receives about one per cent of the sunlight that Earth receives.

2 Tiny Sun

From Saturn, the Sun is ten per cent of the size as seen from Earth.

3 Methane loss

Methane evaporates from lakes back into the atmosphere.

4

4 Giant planet

Saturn's huge bulk is largely hidden by a hazy atmosphere.

7 Solid methane

Methane frosts coat a landscape of rock and water ice.

5 Methane lakes

Methane rains out of the atmosphere at the winter pole to form large lakes.

6 Landscape runoff

Methane rainfall onto highland areas runs downhill and collects in methane lakes.

TITAN THE SECOND EARTH

Mass: 1.3×10^{23} kg (2.9 x 10²³lbs) **Diameter:** 5,150km (3,200 miles) **Parent planet:** Saturn **Discovered:** 1655, Christiaan Huygens

Saturn's largest moon, Titan is unique in the Solar System as the only satellite with a substantial atmosphere of its own - a discovery that frustrated NASA scientists when images from the Voyager probes revealed only a hazy orange ball. The Cassini orbiter was fitted with infrared and radar instruments that pierced the opaque atmosphere, revealing a softened landscape of rivers and lakes that is unlike any other world in the Solar System except for Earth. Despite being larger than Mercury, Titan can only hold onto its thick atmosphere because of the deep cold. Found some 1.4 billion kilometres (0.9 billion miles) from the Sun, the moon's average surface temperature is a freezing -179 degrees Celsius (-290 degrees Fahrenheit).

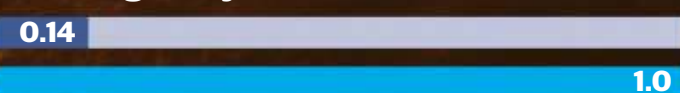
Titan's atmosphere is dominated by the inert gas nitrogen - also the major component of Earth's air - but it gets its distinctive colour, opaque haze and clouds from a relatively small proportion of methane. Amazingly, conditions on Titan are just right for methane to shift between its gaseous, liquid and solid forms, generating a 'methane cycle' rather similar to the water cycle that shapes Earth's climate. In cold conditions methane freezes onto the surface as frost and ice. In moderate temperatures it condenses into liquid droplets and falls as rain that erodes and softens the landscape before accumulating in lakes, while in warmer regions it evaporates and returns to the atmosphere.

Titan experiences changing seasons very similar to those on our planet, though its year is 29.5 Earth years. Temperatures at the winter pole seem to favour rainfall, so the lakes migrate from one pole to the other over each Titanian year. With all this activity, Titan is an intriguing target in the search for extraterrestrial life, though most biologists find it hard to envision organisms that could exist in such harsh and chemically limited conditions, and most agree that Titan's watery inner neighbour Enceladus offers more promising prospects for life.

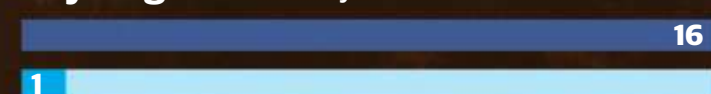
MEASURING UP TITAN

■ Titan
■ Earth

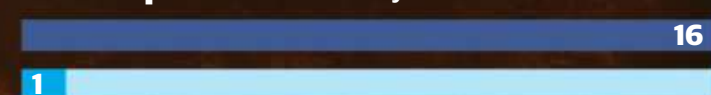
Surface gravity



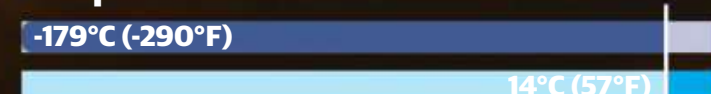
Day length in Earth days



Orbital period in Earth days



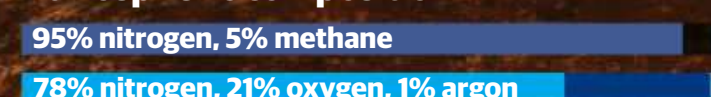
Temperature



Atmospheric pressure



Atmospheric composition



MIRANDA THE CHISELLED SATELLITE

Mass: 6.6×10^{19} kg (1.5 x 10²⁰lbs)

Diameter: 470km (292 miles) **Parent planet:** Uranus

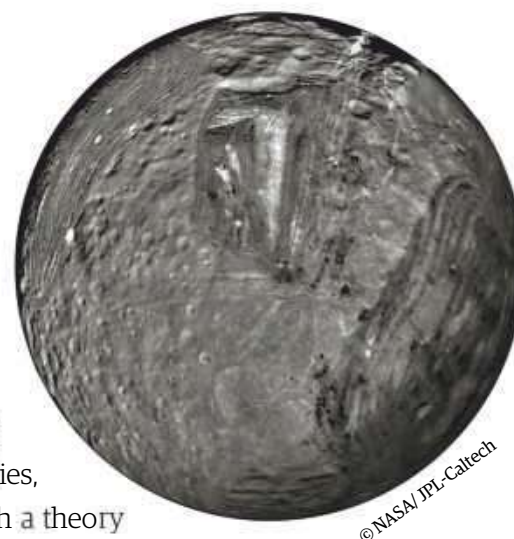
Discovered: 1948, Gerard Kuiper

Miranda is one of the strangest worlds in the Solar System. Voyager images revealed an extraordinary patchwork of terrains, seemingly put together at random. Some parts are heavily cratered and some relatively uncratered - indicating their youth, as they have been less exposed to bombardment. One prominent feature is a pattern of concentric ovals resembling a race track, while elsewhere parallel V-shapes form a chevron-like scar.

An early theory to explain Miranda's jumbled appearance is that it is a Frankenstein world - a collection of fragments from a predecessor moon that coalesced in orbit around Uranus. Astronomers wondered whether Miranda's predecessor might have been shattered by an interplanetary impact, and whether this cataclysmic event might

somehow be linked to Uranus' own extreme tilt. Further studies, however, have shown that such a theory comes up short when trying to explain Miranda's mix of surface features, and the right kind of impact is unlikely. Instead it seems plausible that tidal forces are to blame.

Today Miranda follows an almost-circular orbit, but in its past its orbit was in a 'resonant' relationship with larger moon Umbriel. This brought the two moons into frequent alignments that pulled Miranda's orbit into an elongated ellipse that experienced extreme tidal forces. Pushed, pulled and heated from within, its surface fragmented and rearranged itself before the moons moved again and Miranda's activity subsided.



PAN AND ATLAS THE FLYING SAUCERS

Mass:

4.9×10^{15} kg (1.1 x 10¹⁶lbs) and

6.6×10^{15} kg (1.6 x 10¹⁶lbs)

Diameter:

Average of 28km (17 miles)

and 30km (19 miles)

Parent planet: Saturn

Discovered: 1990 and

1980, Voyager 2

Saturn's moons Atlas and Pan are the smallest moons in the Solar System. However, despite their size their influence can be seen clearly from Earth in the form of the prominent 'gap' they create in the planet's ring system.

These two tiny worlds are perhaps the best known examples of shepherd moons - small satellites that orbit in or around the ring systems of the giant planets. As the name suggests, when coupled with the influence of distant outer moons, such satellites help to herd the particles orbiting in the ring system together while 'clearing out' others. Pan is responsible for creating the Encke Gap, a prominent division in Saturn's bright A Ring, while Atlas orbits just outside the A Ring.

The most intriguing property of both worlds is their smooth shape, resembling a walnut or a flying saucer. Experts believe the moons are blanketed in small particles swept up as they keep the space between the rings clear. As most of the particles orbit in a plane one kilometre (0.6 miles) thick, they tend to pile up around each moon's equator, building a distinctive equatorial ridge.

MIMAS THE REAL-LIFE DEATH STAR

Mass: 3.8×10^{19} kg (8.4 x 10¹⁹lbs) **Diameter:** 396km (246 miles) **Parent planet:** Saturn **Discovered:** 1789, William Herschel

When NASA's Voyager space probes sent back the first detailed images of Mimas in the 1980s, scientists and the public were shocked by its resemblance to the Death Star space station from the *Star Wars* films. A huge crater - named after William Herschel, who discovered the moon in 1789 - dominates one hemisphere, and is almost the exact size and shape of the planet-killing laser dish dreamt up by George Lucas many years before. But Mimas has more to offer than pop-cultural references.

Death Star crater

If Mimas was scaled up to the size of Earth, its giant crater Herschel would be as wide as Australia. The crater was originally far deeper.

Towering peak

Herschel's central peak rises six kilometres (3.7 miles) above the crater floor - it's as high as Mount Kilimanjaro.

Crater variation

Craters around its south pole are half the size of those elsewhere, suggesting this was probably resurfaced with fresh ice early in Mimas' history.

Mimas is the innermost of Saturn's substantial moons - orbiting closer than Enceladus but further out than Pan and Atlas - and with a diameter of just 396 kilometres (246 miles), it's the smallest object in the Solar System known to have pulled itself into a spherical shape from its own gravity. Some larger Solar System objects haven't quite managed this, and most astronomers agree that it's only possible for Mimas because of the moon's low density - just 15 per cent greater than water.

Cracked surface

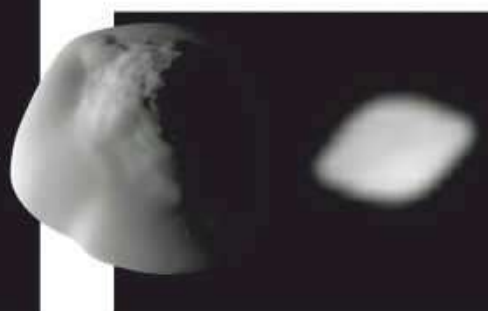
Deep chasms were likely created in the formation of Herschel. Scaled up to the size of Mars, they would rival the Valles Marineris canyons.

Colour changes

Enhanced-colour images show slight variations in the surface: a slightly greenish hue overlaid with blue around Herschel.

Rugby ball core

Tidal forces have given it an ellipsoidal shape, with the axis pointing towards Saturn ten per cent longer than the axis from pole to pole.



EXTINCTION BY SUPERNOVA

Earth's fossil record suggests its ozone layer took a protracted beating

One of the worst extinction events in Earth's history may have been triggered by a supernova, the violent death of a distant star.

About 75 per cent of all species on Earth died out at the end of the Devonian Period, nearly 360 million years ago. Rocks from this era preserve many thousands of spores that appear to be scorched by ultraviolet (UV) radiation, indicating that something went seriously wrong with our protective ozone layer.

The destructive force may have come from very far afield. "Earth-based catastrophes such as large-scale volcanism and global warming can destroy the ozone layer too, but evidence for those is inconclusive for the time interval in question," said Brian Fields, a professor of physics and astronomy at the University of Illinois at Urbana-Champaign. "Instead we

propose that one or more supernovae, about 65 light years away from Earth, could have been responsible for the protracted loss of ozone."

"To put this into perspective, one of the closest supernova threats today is from the star Betelgeuse, which is over 600 light years away - well outside the kill distance of 25 light years," said Adrienne Ertel, a graduate student in Fields' research group.

Supernovae, which end the lives of giant stars, can hit Earth life with a powerful one-two punch. Highly energetic UV, X-ray and gamma radiation delivers the first wallop, and the second comes from swarms of charged particles called cosmic rays that are accelerated to tremendous speeds by the explosion. This combo can damage Earth's ozone layer for 100,000 years or so.

Fossil evidence suggests that biodiversity decreased substantially for about 300,000 years

at the end of the Devonian, often called the 'Age of Fishes' because of its tremendous fish diversity. The Late Devonian extinction may have involved several different dramatic events - perhaps two or more nearby supernovae. "This is entirely possible," said Jesse Miller, another graduate student in Fields' lab. "Massive stars usually occur in clusters with other massive stars, and other supernovae are likely to occur soon after the first explosion."

The team suggested a way to test the hypothesis: look for the radioactive isotopes plutonium-244 and samarium-146 in rocks and fossils from the Late Devonian. Isotopes are versions of chemical elements with different numbers of neutrons in their nuclei. "Neither of these isotopes occur naturally on Earth today, and the only way they can get here is via cosmic explosions," said Zhenghai Liu, also at Illinois.

Such a search has not yet happened. Though Fields and his team aren't the first researchers to find possible links between supernovae and extinction events. For example, a different team recently proposed that a supernova contributed to the minor mass extinction at the end of the Pliocene Epoch about 2.6 million years ago.

The Late Devonian and Late Cretaceous events are two of the five mass extinctions that scientists have traditionally recognised. However, there's a growing consensus that we're now living through a sixth mass extinction - one caused primarily by humanity, with global warming and habitat destruction two of the biggest drivers.

Above: The supernova is estimated to be 65 light years away

"SUPERNOVAE COULD HAVE BEEN RESPONSIBLE FOR THE PROTRACTED LOSS OF OZONE" BRIAN FIELDS

DARK STARS

These cosmic creators, powered by dark matter, could be responsible for our existence, along with the appearance of today's universe

Reported by Amanda Doyle

A

star dies. A sudden flash of light signifies the end in a supernova explosion. This, however, is only part of the life cycle of stars, as the rich materials created during the death throes of the star are ejected into space by the supernova.

When the next generation of stars form, they sweep up the leftovers of the supernova, accreting the metals that the dying star produced - metals being the term that astronomers use for anything heavier than hydrogen and helium. Metals are important; without them, the disc of gas and dust surrounding a newly forming star could not create rocky planets. But if new stars recycle the metals produced in the deaths of old stars, what did the very first stars do?

The universe began with the Big Bang, which created the gases hydrogen and helium, trace amounts of lithium and perhaps beryllium as well. Matter began to clump together, pulling in ever more material through gravitational attraction. It may have been dark matter - the mysterious substance that has yet to be directly detected - that began to accumulate first. This then drew in the ordinary matter, the stuff we can see, such as hydrogen and helium. Together the dark and ordinary matter created what is known as a 'minihalo', although the name is somewhat misleading, as minihalos had masses around a million times that of our Sun.

It was in the minihalos that the first stars were born 200 million years after the Big Bang.

They're not dark

Despite their name, these early members of our universe are not dark – they would have blazed brilliantly, lighting up their surrounding area with a luminosity about a billion times brighter than our Sun.

They're likely to be invisible now

Dark stars are unlikely to have survived to what we perceive to be the modern era of the universe – at least in terms of their high luminosity. If they are visible, they could be detected from their gamma ray, antimatter and neutrino emissions.

WHAT ARE DARK STARS?

They're likely to have been the first 'stars'

During the early days of our universe, usual stars were unable to form. Instead, dark stars are thought to have come from enormous clouds of hydrogen and helium ranging between four and 2,000 astronomical units (AU) – one AU is equivalent to the average distance between the Earth and Sun.

They were powered by dark matter

Dark stars are thought to have comprised of mostly normal matter, much like the stars that we can see in the universe today. However, within dark stars a high concentration of dark matter – likely in a neutrino form – would have annihilated, causing illumination.

Above: Dark matter first assembled into clumps and filaments before attracting ordinary matter to it and then forming the first stars

The first stars are known as Population III stars, and none have ever been observed, as they are too faint. The first stars had to make do with what they had available, and formed from clouds containing only hydrogen and helium. When they died in supernovae explosions, they produced the first metals for the subsequent population of stars, Population II, which have a small proportion of metals. These went on to birth the metal-rich Population I stars we have today.

The dark matter in the minihalo may have done more than bring elements together – it might also have been present deep within the first stars. These stars are known as 'dark stars', due to the dark matter within them, although they would have actually shone very brightly.

Everything that we can see and detect – the stars and galaxies – only makes up a puny five per cent of the universe, whereas dark matter comprises 25 per cent. The rest is made of dark energy, another oddity thought to be responsible for accelerating the expansion of the universe. Dark matter does not interact with ordinary matter and it does not produce any light. We only know that it must be there as its immense gravitational force tugs on ordinary matter.

One of the leading theories attempting to explain the invisible mass in the universe is a hypothetical particle known as a WIMP – a weakly interacting massive particle. 'Weakly' interacting refers to their relationship with ordinary matter. However, they would still interact with themselves. In fact, if two WIMPs collided with each other they would destroy each other in a process known as annihilation. This is because theories predict that WIMPs are their own 'antiparticles'.

Ordinary matter has antiparticles, which are particles that have the same properties but are of opposite charge. Atoms consist of a nucleus surrounded by electrons. Electrons have a negative charge, and if they meet a particle known as a

“THE STANDARD SCENARIO FOR THE FORMATION OF THE FIRST STARS DOES NOT RELY ON DARK MATTER ANNIHILATION” ERIK ZACKRISSON

positron - with a positive charge - the electron and the positron will catastrophically annihilate each other.

A side effect of annihilation is that it produces energy. As a star begins to form in a minihalo, the collapsing material will contain hydrogen, helium and WIMPs. At first the energy produced by the colliding WIMPs leaks out into space, but when the density of hydrogen is high enough, it traps the energy from the WIMPs inside the star. Even though the WIMPs only account for a tiny fraction of the mass of the star, they are so efficient at energy production that they can power a dark star for millions, or even billions of years.

It is still uncertain if all of the first stars were ordinary Population III stars with no dark matter, dark stars or if both types of stars coexisted. "The standard scenario for the formation of the first stars does not rely on dark matter annihilation," says Erik Zackrisson from Uppsala University in Sweden. "Dark stars are simply seen as an exotic alternative to the standard formation route."

Ordinary stars are powered by fusion, the process that converts hydrogen into helium in the core of the star. The Population III stars would have been massive, weighing in at around 100 times the mass of our Sun. However, they were also very hot, and this limited the amount of material that they could accrete. Dark stars, on the other hand, were

Right: NASA technicians complete a series of cryogenic tests on six James Webb Space Telescope beryllium mirror segments

much cooler. This meant that they could accrete substantially more of the surrounding material and could theoretically keep growing as long as there was enough dark matter to fuel them. Dark stars could have reached masses up to a million times that of the Sun, with a luminosity a billion times brighter than it.

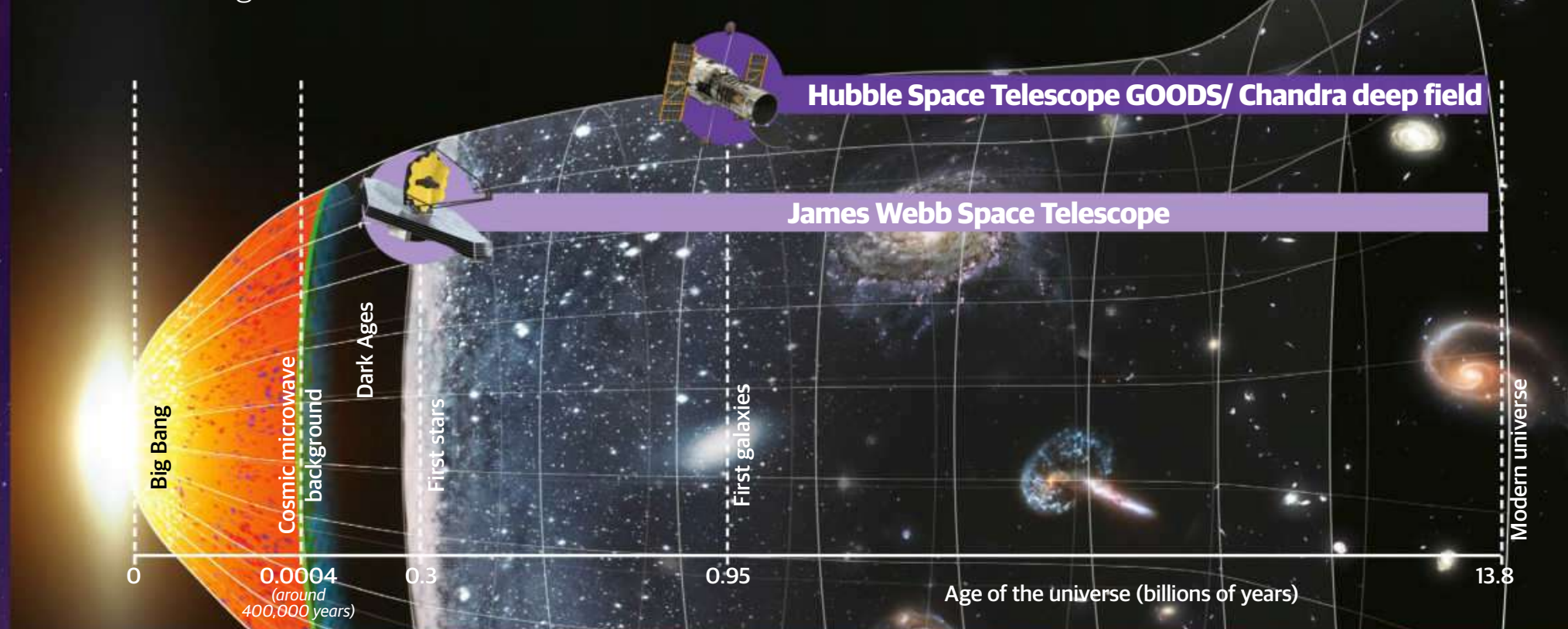
As the saying goes, all good things must come to an end, and the WIMPs will have eventually annihilated each other. Unlike Population III stars,

which end their lives as supernovae, dark stars are so massive that they are fated to become a black hole. The smaller dark stars could take a detour on the way to oblivion by briefly igniting as an ordinary fusion-powered star. When this happened, the star would contract and become hotter. The hydrogen would have quickly been consumed in the belly of the star, and when the fusion engine could no longer support the star, the inevitable collapse into a black hole would have occurred.



OBSERVING DARK STARS

NASA's James Webb Space Telescope (JWST) will be able to see further back in time than the long-serving Hubble, meaning that it could detect dark stars



MAKING OUR SUN'S DARKER COUSIN

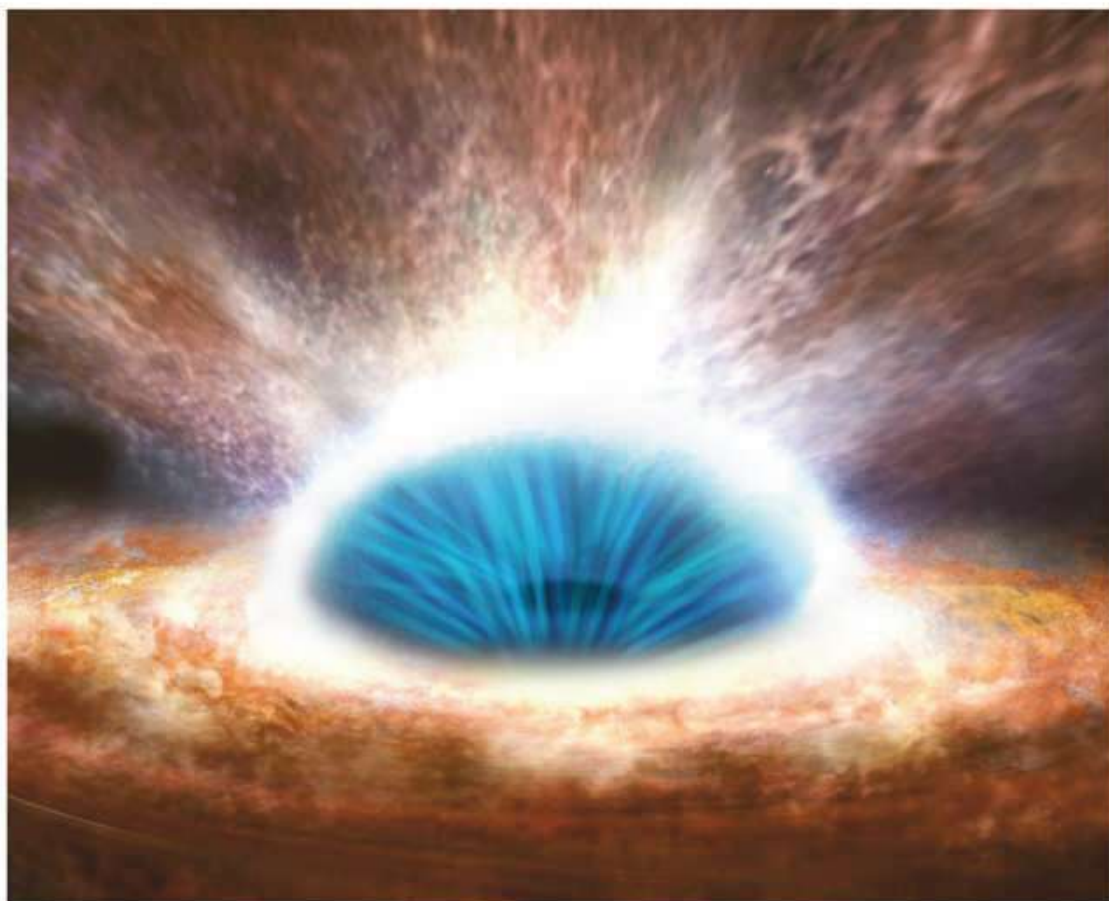
Formed not long after the Big Bang, these brilliant members of the early universe aren't your conventional stars

THE EARLY UNIVERSE

After the birth of the cosmos some 13.8 billion years ago, the universe expanded. Within less than a second, temperatures rose extremely high, and a soup of particles made up the observable cosmos that we see today. Some 70,000 years after the Big Bang, dark matter supposedly dominates.

THE FIRST 'STARS'

It's thought that dark stars began with a mass similar to our Sun. Eventually they grew to millions of times its mass, before the true first stars burst into existence. They would have been surrounded by enormous clouds of hydrogen and helium, hundreds of thousands of kilometres across.

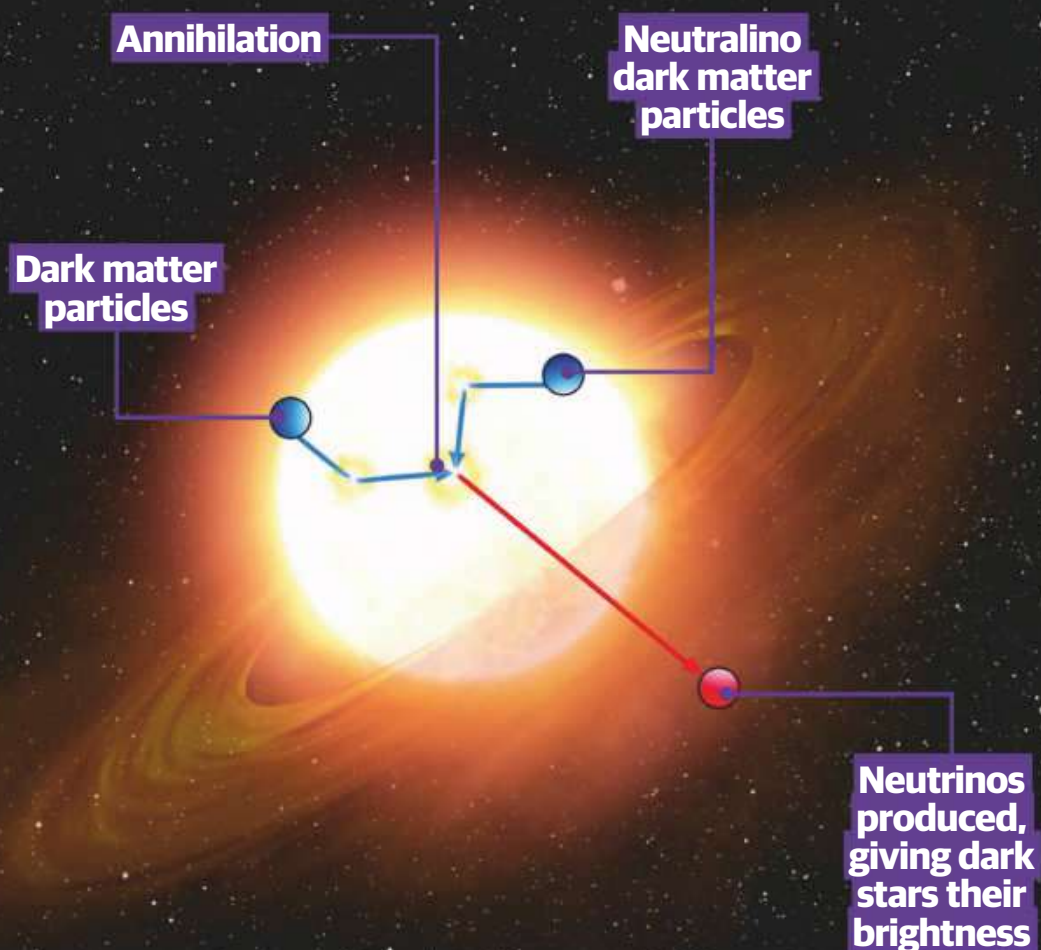


Left: Dark stars would have inevitably collapsed into black holes

Right: Artist's impression of a dark star viewed in infrared

The most massive of the dark stars would have bypassed the fusion stage altogether, collapsing straight into a black hole. These black holes were so massive that they offer a solution to a problem that had previously puzzled scientists. Supermassive black holes, which can be billions of solar masses, exist at the centre of every galaxy, and are known to have existed only a billion years after the Big Bang. However, an ordinary star collapsing into a black hole would need more than a few hundred million years to gobble up enough material to become a supermassive black hole. "Ordinary stars cannot do it, because ordinary stars are too small," explains Katherine Freese from the University of Texas at Austin. "Dark stars, on the other hand, can grow to become a million times as massive as the Sun, and then when they run out of fuel they collapse into million-solar-mass black holes, the perfect seeds for monstrous supermassive black holes."

The supermassive WIMP-powered dark stars could only have formed in the minihalos of the



DARK MATTER ANNIHILATION

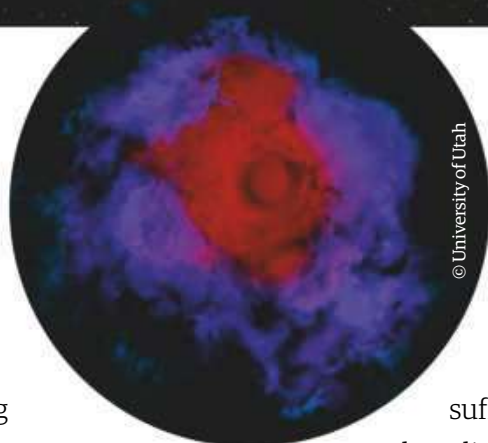
The reactions occurring in dark stars would have been the annihilation between the neutralino dark matter and their counter dark matter particles. With such a high concentration of dark matter, it's thought that heat generated by reactions within them would have stopped them from collapsing to make modern stars.

A BRIGHT DARK STAR

The annihilation processes inside the dark star cause it to shine brightly with a luminosity that's billions of times brighter than the Sun. It's possible that these stellar objects could still exist today, albeit as embers that require the help of future telescopes like the James Webb Space Telescope to see them.

early universe, when the density of dark matter was much higher than it is today. Over time, as the universe expanded, everything became more spread out, so there are no longer minihalos capable of birthing supermassive dark stars.

This confines them to the early universe, which also means that they are at a great distance from us here on Earth. Astronomers use the term 'redshift' to denote distance in cosmology, as the light from a distant object will get shifted towards the red end of the spectrum, permitted that it's moving away from us. Dark stars only exist at high redshifts, making them an observing challenge. The infrared Ultra Deep Field images taken by Hubble were used to look for dark stars, but none were found. This doesn't necessarily mean they don't exist, as there could be less luminous dark stars lurking beyond Hubble's vision. The upcoming James Webb Space Telescope (JWST) - due to be launched in October



2021 - will outdo its predecessor by looking further back in time.

"If dark stars do exist, and are sufficiently massive, numerous and long-lived, then the JWST certainly has a decent chance of confirming their existence at high redshifts," says Zackrisson. "However, since the distribution of dark star properties hinges on both the properties of the dark matter particles and the cosmological evolution of the dark matter halos that host them, success is by no means guaranteed."

Even if the JWST can't detect individual dark stars, it might still be able to detect their overall glow. Just as individual street lights all add up to produce an infuriating yellow glow over cities, light from stars and galaxies accumulates into what is known as the extragalactic background light (EBL). The EBL has already been mapped to a certain extent, but the improved measurements from the JWST will help to sniff out the contributions from dark stars, which hasn't been manageable before.

"WHEN DARK STARS RUN OUT OF FUEL THEY COLLAPSE INTO MILLION-SOLAR-MASS BLACK HOLES" KATHERINE FREESE

While WIMP annihilation can theoretically provide enough fuel to keep a dark star going for billions of years, it is unlikely that any of the dark stars from the early universe are still around today. However, it is possible that a new generation of dark stars could exist where dark matter concentrations are still somewhat high, such as in the centre of galaxies. As there is less dark matter in galactic centres compared to the minihalos of the ancient universe, the new generation of dark stars would be much less massive - only equivalent to that of our Sun - and will never be able to rival the glory days of the first stars.



Below: The Hubble Ultra Deep Field was used to search for dark stars in the early universe

© NASA/ESA & Hubble

Solar-mass dark stars near the galactic centre would not have formed while trapping WIMPs inside them, but rather by capturing some of the dark matter that resides at the centre of the galaxy. When this happens, dark matter heating takes over from ordinary fusion, and the stars cool and expand. Not only would this make them appear younger than they actually are, but it could also extend their lifetimes exponentially. If there was enough dark matter for them to continuously accrete it, the dark stars could exist indefinitely. Everlasting dark stars could bookend the lives of some stars in the universe.

Another possibility is that ‘dead’ stars such as neutron stars or white dwarfs at the galactic centre could gather enough WIMPs in order to trigger dark matter heating. These stars would otherwise become fainter over time, but with a new heating source they would get a new lease of life and appear strangely younger and hotter than expected.

Understanding the early years of our wondrous universe and how the first stars came to be is crucial to understanding what we see around us today, as well as understanding the more complex objects and phenomena in the Solar System. It is a murky period that is difficult to observe, but with the next generation of telescopes, such as the JWST, it might finally be possible to detect both the supermassive dark stars of the early universe and their less impressive cousins in the galactic centre.

Discovering whether it was Population III stars, dark stars or both that were the first stars to form in the universe will have a profound effect on cosmology. It won't be long before we can shed some light on these dark members of the cosmos.



Amanda Doyle
Space science writer
Amanda holds a PhD in astrophysics, where she analysed the spectra of exoplanet host stars. She is the former editor of *Popular Astronomy*.

STAR COMPARISON CHART

	Mass	Luminosity	Radius
Sun	 1.99x10 ³⁰ kg	 3.83x10 ²⁶ W	 695,700 kilometres
Dark stars	 Millions of times the Sun's	 Billions of times the Sun's	 Likely smaller than the Sun
Blue supergiant stars	 Up to 20 times the Sun's	 10,000 to 60,000 times the Sun's	 Up to 78 times the Sun's
Red supergiant stars	 10 to 30 times the Sun's	 1,000 to 80,000 times the Sun's	 100 to 1,650 times the Sun's
Red giant	 0.3 to 10 times the Sun's	 100 to 1,000 times the Sun's	 15 to 100 times the Sun's
Yellow dwarf	 0.8 to 1.4 times the Sun's	 0.5 to 5.0 times the Sun's	 0.96 to 1.4 times the Sun's
Orange dwarf	 0.45 to 0.8 times the Sun's	 0.08 to 0.6 times the Sun's	 0.7 to 0.96 times the Sun's
Red dwarf	 0.07 to 0.5 times the Sun's	 0.0001 to 0.08 times the Sun's	 0.13 to 0.7 times the Sun's

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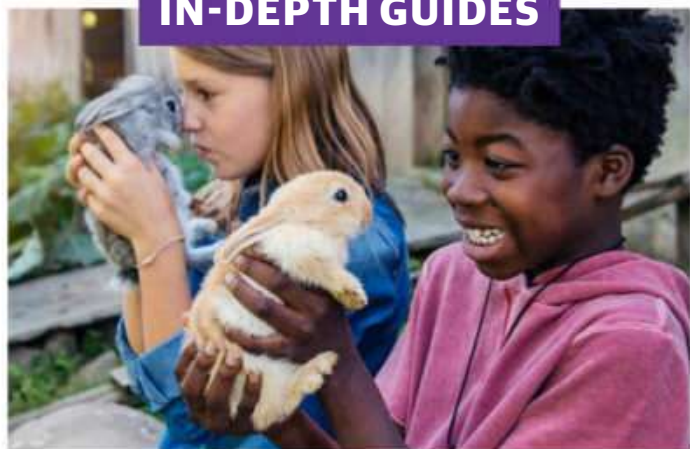
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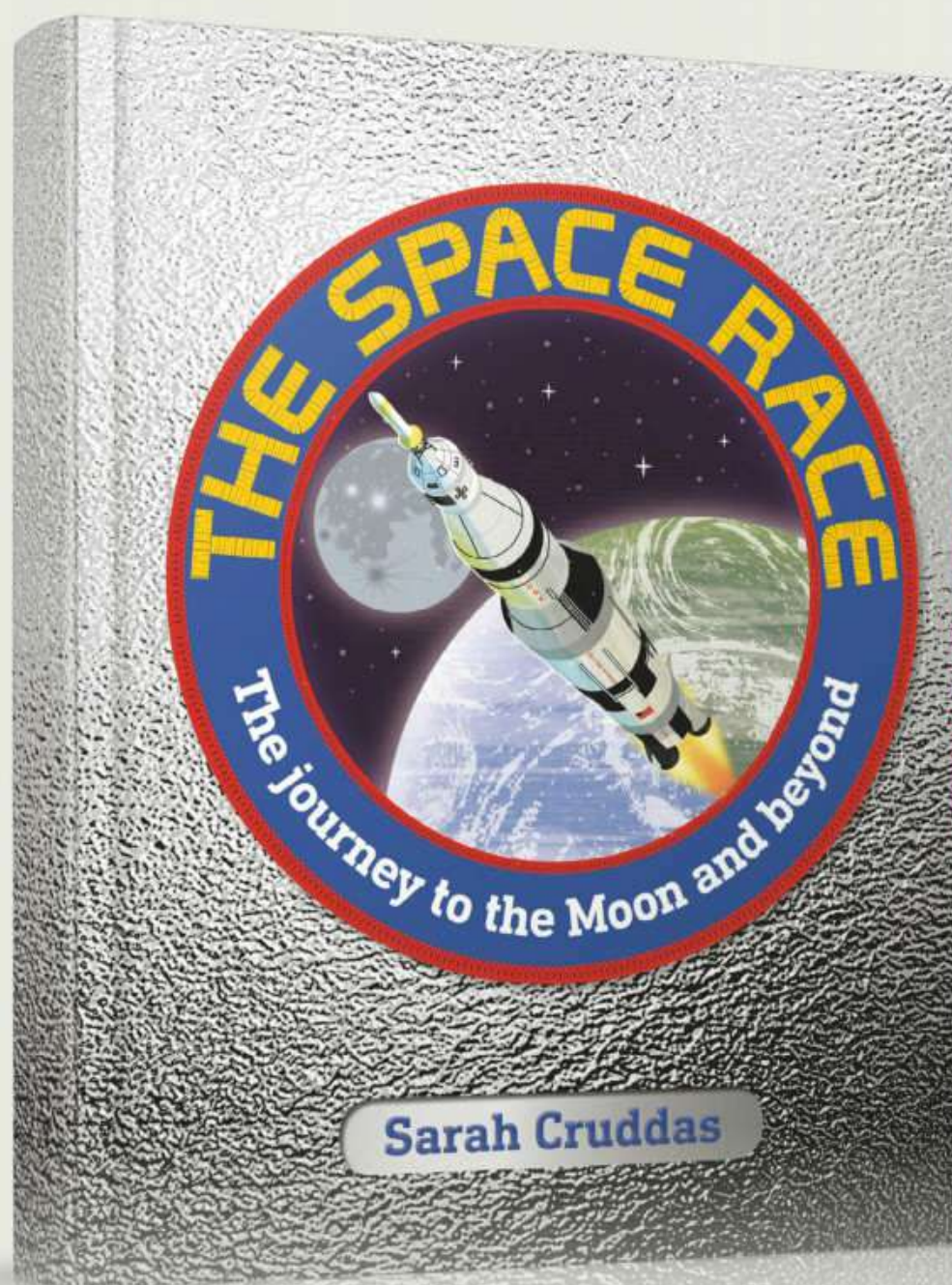


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STAR PROFILE

Betelgeuse

The famous red giant will soon be coming to an explosive end

Betelgeuse, or Alpha Orionis, has had an eventful 8.5 million years, and astronomers predict it has less than a million years left. If you were to go outside and stare out at the night sky, you'd recognise Betelgeuse quite easily within Orion, shining with an apparent magnitude of +0.5. However, this figure has been known to vary due to the star's instability, which causes pulsations in the star's outer layers and in turn expels material into its surrounding environment.

The star is relatively nearby at just 642 light years away, and exists as an enormous red supergiant star. If it were placed in the centre of our Solar System, its outer surface could stretch to around the orbit of Jupiter. This Herculean size is due to an imbalance within the star's interior. Towards the end of any star's life, a lifetime of nuclear fusion - the process in which hydrogen fuses into helium within a stellar core and releases energy - has inevitably depleted the

hydrogen fuel source that keeps the fire burning. This results in overpowering gravity putting strain on the core, which is experiencing a depleting radiation pressure output. This ignites nuclear fusion in the outer layers of the star, and the core then begins to convert helium into heavier elements such as carbon, oxygen and so on. The resultant radiation pressure within Betelgeuse's outer layers has pushed the surface of the star outwards, bloating it into its current supergiant status.

Betelgeuse - like any star - began as a cloud of gas and dust, and was able to gravitationally accrete 15 times the mass of our Sun at a time when Earth was already almost 4 billion years old. Based on microfossil evidence, life in its simplest form had already been around for approximately a billion years. This shows how rapid Betelgeuse's birth and evolution have been. However, this is the usual trend when it comes to stars with significantly more mass than our Sun: the biggest and brightest stars always burn out the fastest.

In the next 100,000 years or so, Betelgeuse will explode in an extraordinary fashion, visible throughout the cosmos. This is known as a supernova, and it starts when the star's core begins to form iron. As nuclear fusion creates elements heavier than helium, there comes a point when iron is formed. If you want to create a heavier element than iron, the process requires energy from its environment, instead of emitting it. This is referred to as an 'endothermic reaction'. This will lead the interior of Betelgeuse to collapse in on itself and ricochet off the iron core, resulting in a supernova explosion. This explosion will light up the sky on Earth, even in broad daylight. This is not a cause for concern, however, as astronomers predict that the resulting shock wave would have to travel for about 6 million years before it came close to Earth. At this point it will have slowed down to be nothing more than a light breeze on the Solar System's protective bubble.



Source: Wikipedia Commons © Igor da Bari

Right:
Betelgeuse
(top left) is
one of Orion's
shoulders

“THE BIGGEST AND
BRIGHTEST STARS
ALWAYS BURN OUT
THE FASTEST”

ATMOSPHERIC
COMPOSITION

70%
HYDROGEN

28%
HELIUM

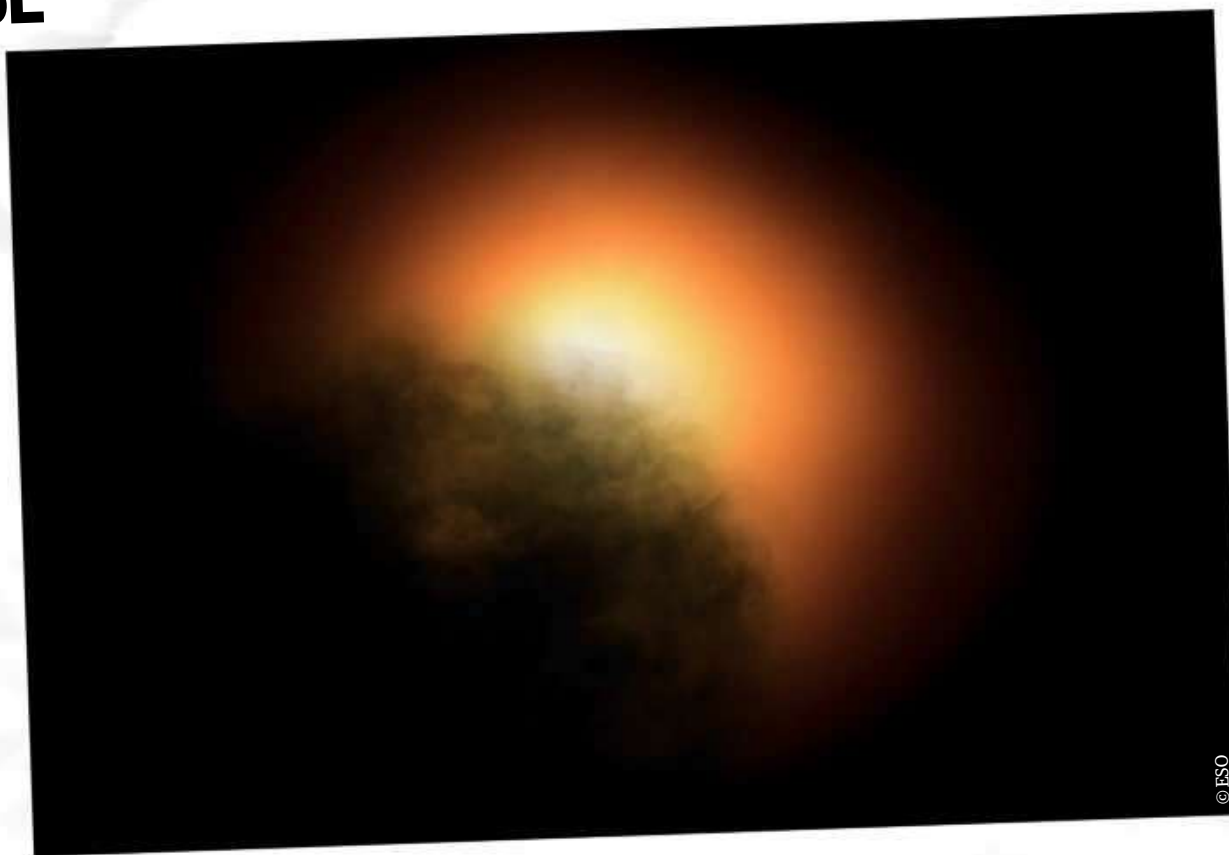
2.4%
HEAVY
ELEMENTS

NEWS FROM BETELGEUSE

Mysterious dimming

In October 2019 astronomers began noticing a gradual dimming to Betelgeuse, an effect noticeable even to the naked eye. With the help of Hubble, astronomers have recently concluded that a huge dust cloud appeared between the star and Earth, blocking out a quarter of the star's surface. By viewing the star using ultraviolet spectroscopy, Hubble mapped a dense, heated cloud of material shifting past the star's atmosphere in the latter months of 2019. This supposedly formed from super-hot plasma emitted due to an upwelling of a large convection cell on the star's surface.

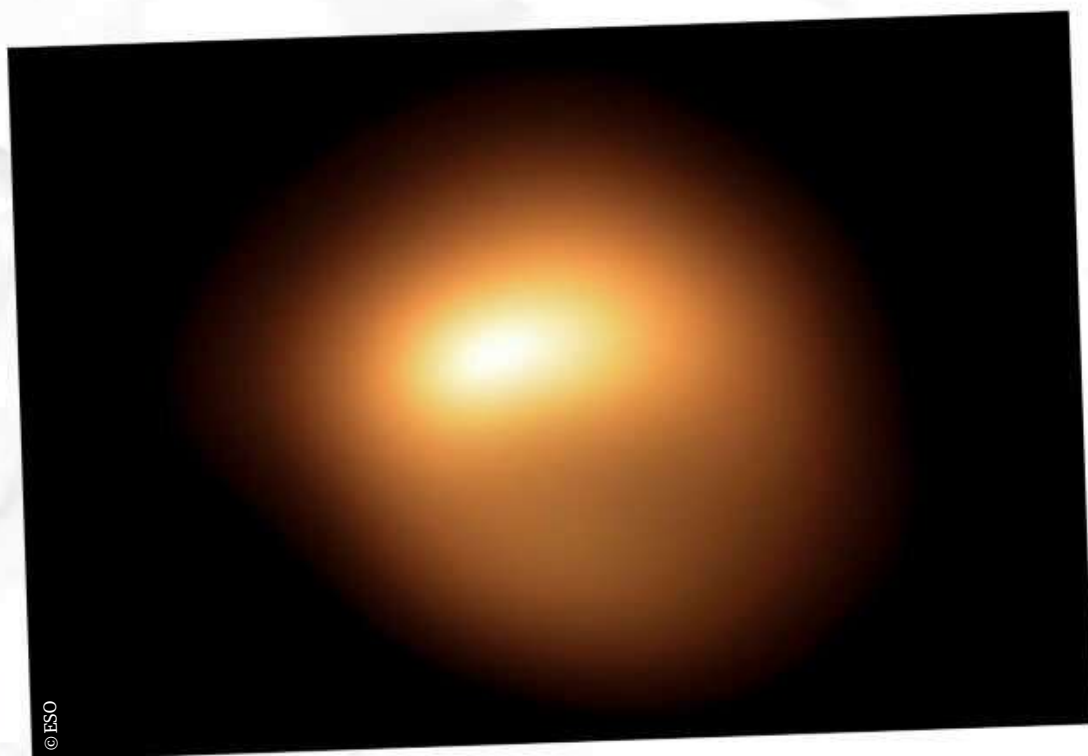
"With Hubble, we see the material as it left the star's visible surface and moved out through the atmosphere, before the dust formed that caused the star to appear to dim," says lead researcher Andrea Dupree, associate director of the Harvard-Smithsonian Center for Astrophysics, Massachusetts. "We could see the effect of a dense, hot region in the southeast part of the star moving outward." Astronomers have attributed this phenomenon to a pulsation cycle, where the star's advanced stage and instability cause the star's convection cells to shrink and grow in size.



Resolving the star's surface

As ground-based telescopes become more advanced, more stars based hundreds, or possibly even thousands, of light years away are going to be imaged and mapped in remarkable detail. As Betelgeuse is relatively nearby and has an enormous surface area, it was recently targeted in December 2019 by the European Southern Observatory's (ESO) Very Large Telescope (VLT). These stunning stellar surface images not only show the fading of the red supergiant, but also its shifting shape.

The lead researcher in this study, Miguel Montargès of the KU Leuven institution in Belgium, suggests there are two explanations. It could be due to powerful stellar activity such as the pulsation cycle, or it could be tied to a related dust ejection in the direction of Earth. Both of these scenarios match up with the Hubble Space Telescope's recent observations, but the space-based telescope cannot provide the same level of surface resolution that the VLT has proven it can provide. "The ESO's Paranal Observatory is one of few facilities capable of imaging the surface of Betelgeuse," says Montargès. "This is the only way we can understand what is happening to the star."



Probing the problems with pulsating stars

With Betelgeuse's sudden dimming stirring up a lot of public attention, more researchers have published work concerning how a star's pulsation will affect the eventual explosion as it approaches the end of its life. This work was published by Jared Goldberg, a physics graduate student at the University of California, Santa Barbara (UCSB), California, Lars Bildsten, director of UCSB's Kavli Institute for Theoretical Physics (KITP) and Gluck professor of physics, and KITP senior fellow Bill Paxton. "We wanted to know what it looks like if a pulsating star explodes at different phases of pulsation," said Goldberg. "Earlier models are simpler because they don't include the time-dependent effects of pulsations."

When it comes to supernovae, an important thing to remember is that the extravagance of the explosion is related to the amount of material in the star. When the star pulsates prior to going supernova, it ejects mass and makes predicting the supernova a harder task. This new research reveals how light emission leaks out from deeper layers within a supernova explosion. "Light from the part of the star that is compressed is fainter," Goldberg explains. "Just as we would expect from a more compact, non-pulsating star." However, light from expanding layers of the star would appear brighter, as expected from a larger, non-pulsating star.



FUTURE EXPLORATION OF BETELGEUSE

Betelgeuse is roughly 642 light years away, meaning that even if a spacecraft was travelling there at the speed of light, it would still take 642 years – and multiple generations of astronauts in one spacecraft – to get to it. This is beyond the realms of modern-day technology and rocketry. Presently the fastest human-made spacecraft is NASA's Parker Solar Probe, which reached a speed of 246,960 kilometres (153,454 miles) per hour as it flew past the Sun. This is still less than 0.023 per cent the speed of light, so the human or robotic exploration of Betelgeuse's stellar system is essentially off the cards for the time being. There are some conceptual ideas for propulsion that could potentially get spacecraft to a speed closer to the speed of light, such as antimatter propulsion, laser-powered ion thrusters or the faster-than-light Alcubierre drive. Sadly these are all conceptual designs, with no weight behind them at this moment in time.

However, ground- and space-based telescopes are continuing to improve with each passing year. As seen with the VLT results, astronomers have already been able to resolve the star's surface to the point where they can see a change in its shape. Soon the world will see the likes of even more powerful telescopes such as the Thirty Meter Telescope, the James Webb Space Telescope, the Giant Magellan Telescope, the Extremely Large Telescope and the Square Kilometre Array. These will reach unprecedented degrees of sensitivity.

All of these telescopes are currently being worked on to receive first light in the 2020s – assuming their respective constructions don't have too many setbacks. This means that in the next decade Betelgeuse will be able to be scrutinised in remarkable detail. Its unusual dimming, its enormous size and its dying breaths will be documented with tremendous excitement.

Below: When completed, the Extremely Large Telescope will be the world's largest optical and near-infrared telescope



BETELGEUSE BY NUMBERS

1,000

times the diameter of the Sun.

3,325
DEGREES CELSIUS

(6,017 degrees Fahrenheit) is the average surface temperature of Betelgeuse.

15%

Starting in 1993 and continuing for 15 years, the radius of Betelgeuse has shrunk by 15 per cent.

140,000

times the luminosity of the Sun.

420

Betelgeuse pulsates, expanding and shrinking on a 420-day cycle.

1988

This star is not to be confused with Tim Burton's 1988 film *Beetlejuice*.

The name Betelgeuse has Arabic origins, but the star has alternative names in Sanskrit, traditional Chinese and Hawaiian.

THE APPARENT EVOLUTION OF BETELGEUSE

- Date:** 0 years
Activity: All that existed prior to the star's birth was a cloud of gas and dust, lost and alone in the depths of space.
- Date:** 0 to 190,000 years
Activity: At some point this cloud began to collapse under its own gravity, forming a tiny core of dust that continued to gradually accrete more and more mass as it became a protostar – a baby Betelgeuse.
- Date:** 190,000 to 290,000 years
Activity: During this period the Betelgeuse protostar accumulated 15 times the mass of the Sun, eventually initiating nuclear fusion and becoming a zero age main sequence star.
- Date:** 290,000 to 8 million years
Activity: For millions of years Betelgeuse was a fraction of the size it is now, burning hydrogen into helium at a tremendous rate. The main sequence phase makes up the majority of a star's life.
- Date:** 8 to 9 million years
Activity: After rapidly burning out its supply of hydrogen, Betelgeuse entered its red supergiant phase, which it exists in now.
- Date:** 9 million years
Activity: After an iron core has formed, as a consequence a supernova will occur, spilling out its layers into the cosmos.
- Date:** Over 9 million years
Activity: The core of what was once a gigantic star will be left behind. This can be one of two things: a neutron star or a black hole. Both exist for an indeterminable amount of time.



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ENTER THE COSMIC BATTLEFIELD VIOLENT UNIVERSE

The cosmos is not the serene place it first appears... it is full of aggressive offenders

Reported by Colin Stuart

As ultraviolet radiation cascades down from space, Earth's place as a life-friendly planet is under threat. The surface of our world is bathed in this high-energy radiation, and it penetrates our oceans to depths of 75 metres (246 feet). The damage is catastrophic. The intense glare fries ocean plankton, and those organisms which survive divert all their energy to repairing their DNA rather than photosynthesising. Oxygen levels then drop as carbon dioxide levels rise. The knockout blow for many larger species comes as dwindling plankton numbers offer scant food resources, with the effect rocketing up the food chain.

Thankfully this fictional future is very unlikely, but what would have caused such devastation? The answer is a gamma-ray burst (GRB). They often emit as much energy in a few seconds as our entire galaxy does in a year. If such a volley of gamma rays were to strike our planet, it would rip molecules in our atmosphere apart, releasing an army of ultraviolet photons to devastate the world's biosphere. Luckily these catastrophic events are rare, particularly in our own Milky Way. In fact, we've never observed one in our galaxy. Even if one were to go off, it would have to be aligned almost perfectly with Earth. However, studying them reveals just how violent our universe can be.

THE MOST DESTRUCTIVE OBJECTS

Gamma-ray bursts

Caused either when a massive star collapses into a black hole or when two neutron stars collide, the total gamma-ray energy emitted is 100 trillion trillion times more than the largest nuclear weapon ever tested on Earth.



© NASA

Supernovae

An explosion which occurs upon the death of a star, supernovae are at least eight times more massive than our Sun. A supernova can commonly release twice the amount of energy as a typical gamma-ray burst.



© ESO

Hypernovae

Some supernovae can be particularly brutal. Known as hypernovae, these events are associated with the origin of long gamma-ray bursts. The amount of energy released can be 100-times greater than an ordinary supernova.



© NASA

Quasars

The most energetic form of active galactic nuclei, a single quasar can release as much energy in a second as the Sun can release in 100,000 years. They can even be 100 times as luminous as an entire galaxy.



© ESO

Magnetars

A particularly vicious form of neutron star, the strength of a magnetar's magnetic field is a billion-times stronger than any magnet created by scientists on Earth. Such a set-up fires high-energy X-rays and gamma rays into space for 10,000 years.



© ESO



Left: A giant jet of radiation extending out from the active centre of the galaxy M87

© NASA/ESA & Hubble

As the majority of GRBs observed by astronomers are in distant galaxies, working out exactly what causes them is notoriously tricky. However, most researchers agree that they are related to the death of stars. When a star at least eight-times bigger than the Sun begins to die, it alters the way it fuels itself. During the main chunk of its lifetime it was converting hydrogen into helium via nuclear fusion. However, it now starts to fuse helium into carbon and begins to bloat outwards. The core continues to fuse heavier and heavier elements until it creates a dense, iron core. The core then collapses under its own weight before rebounding and sending a shock wave through the star's outer layers, causing it to explode as a Type II supernova – an event so energetic it can outshine all the stars in a galaxy and be seen even during daylight hours.

GRBs are associated with a particularly vicious form of supernova, known as a hypernova, which can be up to 50 times more energetic than the

ordinary variety. They are thought to form when the iron core of a star at least 30 times more massive than the Sun collapses to form a black hole. Twin jets of energetic radiation surge away from the region close to the black hole, and the gamma rays are believed to be produced by collisions between the jets and the outer layers of the star.

At least that's the favoured origin mechanism for around 70 per cent of observed GRBs – those that last longer than two seconds. These are known as long gamma-ray bursts. However, roughly 30 per cent of GRBs are much shorter, typically lasting just 0.2 seconds. Rather than the collapse of a single star, these short gamma-ray bursts are believed to originate from the collision of two neutron stars – the remnants of dead stars smaller than those which form black holes. The size of a city, a neutron star is so dense that a teaspoon full of its material weighs more than a mountain range, and their magnetic fields can be a trillion-times stronger

AT THE HEART OF A MONSTROUS MAGNET

1 Magnetic field

Magnetars are known for their extremely powerful magnetic fields, which produce high-energy X-ray and gamma-ray bursts. These magnetic fields are hundreds of millions times stronger than any human-made magnet on Earth.

2 Outburst

The fireball, produced by magnetic field decay, ejects intense flashes of high-energy electromagnetic radiation. These giant flares leave the surface of the magnetar at the speed of light, and their radiation has even been recorded on Earth.

3 Solid crust

This outer layer is often only 500 metres (1,640 feet) thick. Eventually it fractures under the extreme magnetic stress. After all, a magnetar placed at the distance of the Moon could wipe all the credit cards on Earth. X-rays are then released by the resulting fireball.

4 The fluid layer

Extending out from the core over a distance of approximately six kilometres (3.7 miles), this heavy fluid interior is mostly made of neutrons, with a scattering of other atomic particles. Here the process of convection carries heat away from the core.

5 The solid core

Measuring just three kilometres (1.8 miles) across, the central core of a magnetar is made of subatomic particles called quarks – the same building blocks from which protons and neutrons are constructed.

"A NEUTRON STAR IS SO DENSE THAT A TEASPOON OF ITS MATERIAL WEIGHS MORE THAN A MOUNTAIN RANGE"

than our Sun's. Computer simulations show that when two neutron stars spiral inwards towards each other they merge to form a black hole. The magnetic fields merge, too, and the overall strength of magnetism is boosted by a thousand times. Eventually the new black hole's magnetic field aligns into jets, which can power a short GRB.

Not content with being responsible for these mighty events, neutron stars are also thought to be behind another of the universe's rogues' gallery of violent offenders: magnetars. Souped-up versions of single neutron stars, they boast a significantly stronger magnetic field. It is estimated that ten per cent of neutron stars end up as this enhanced variety. With a rotational period of at least one second, they also spin more slowly than their traditional counterparts, which can rotate dozens of times in the same period. Their stronger magnetic field can yield intense flashes of gamma rays and X-rays, but not for long - the typical lifetime of a magnetar is just 10,000 years, a blink of an eye in astronomical terms. There are thought to be at least 30 million extinct magnetars in our Milky Way galaxy alone.

Sticking with the merging remnants of dead stars, there is another type of supernova which is sometimes the result of two white dwarfs colliding together. Less massive than neutron stars or black holes, white dwarfs are the leftovers from stars about the size of the Sun. If two Sun-like stars were orbiting around each other in a binary system, when they both die the resulting white dwarfs can collide with each other. However, there is a limit to how massive a single white dwarf can be - known

1 Tiny but mighty

The catastrophic collapse of a star into a neutron star squashes both matter and magnetic field into a space about the size of a city. Despite this diminutive size, a neutron star weighs more than the Sun.

2

3 Radio lighthouse

The magnetic field generates beams of energy at the neutron star's poles. Like a lighthouse, these beams rotate with the neutron star, and we can hear them as pulses of radiation with our radio telescopes - hence why they are sometimes called pulsars.

Below: Despite their distance from us, space telescopes can see quasars thanks to their luminosity

2 She's electric

Rotating many times a second, the electric field generated by a neutron star is 30 million-times greater than a lightning bolt. We're talking about a voltage measured in petavolts, which is a quadrillion volts!

3

4

4 Mighty magnetism

The magnetic field of a typical neutron star can be a million-times stronger than Earth's own magnetism. Magnetars, on the other hand, can have magnetic field strengths over a trillion times more than Earth's.

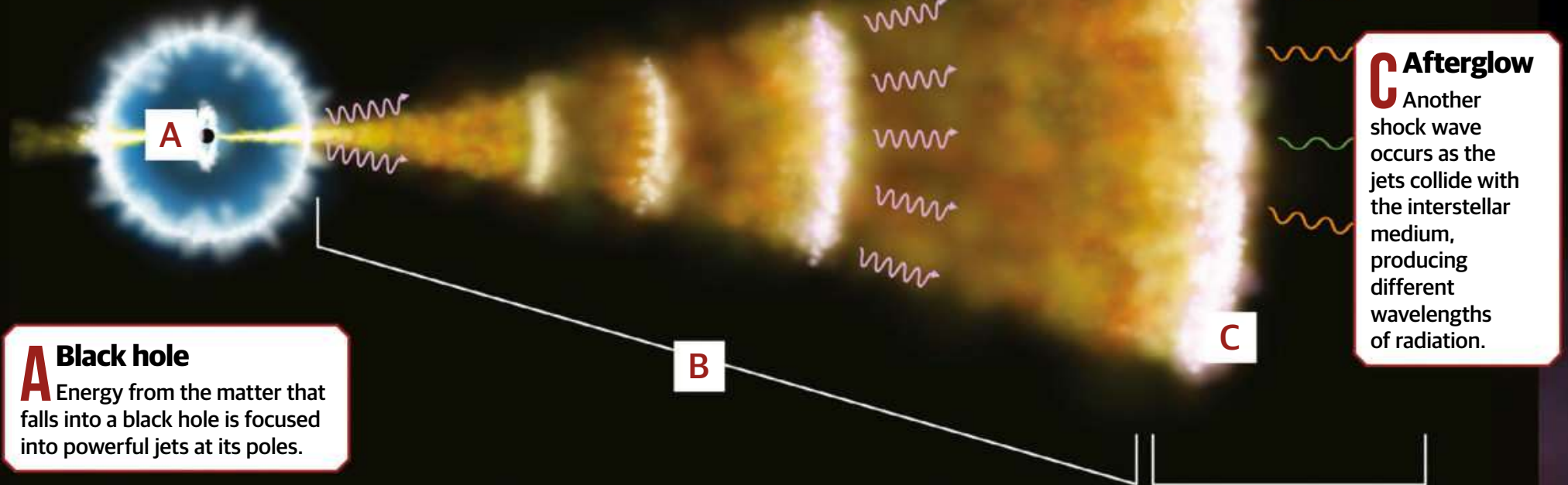
5

5 X-ray source

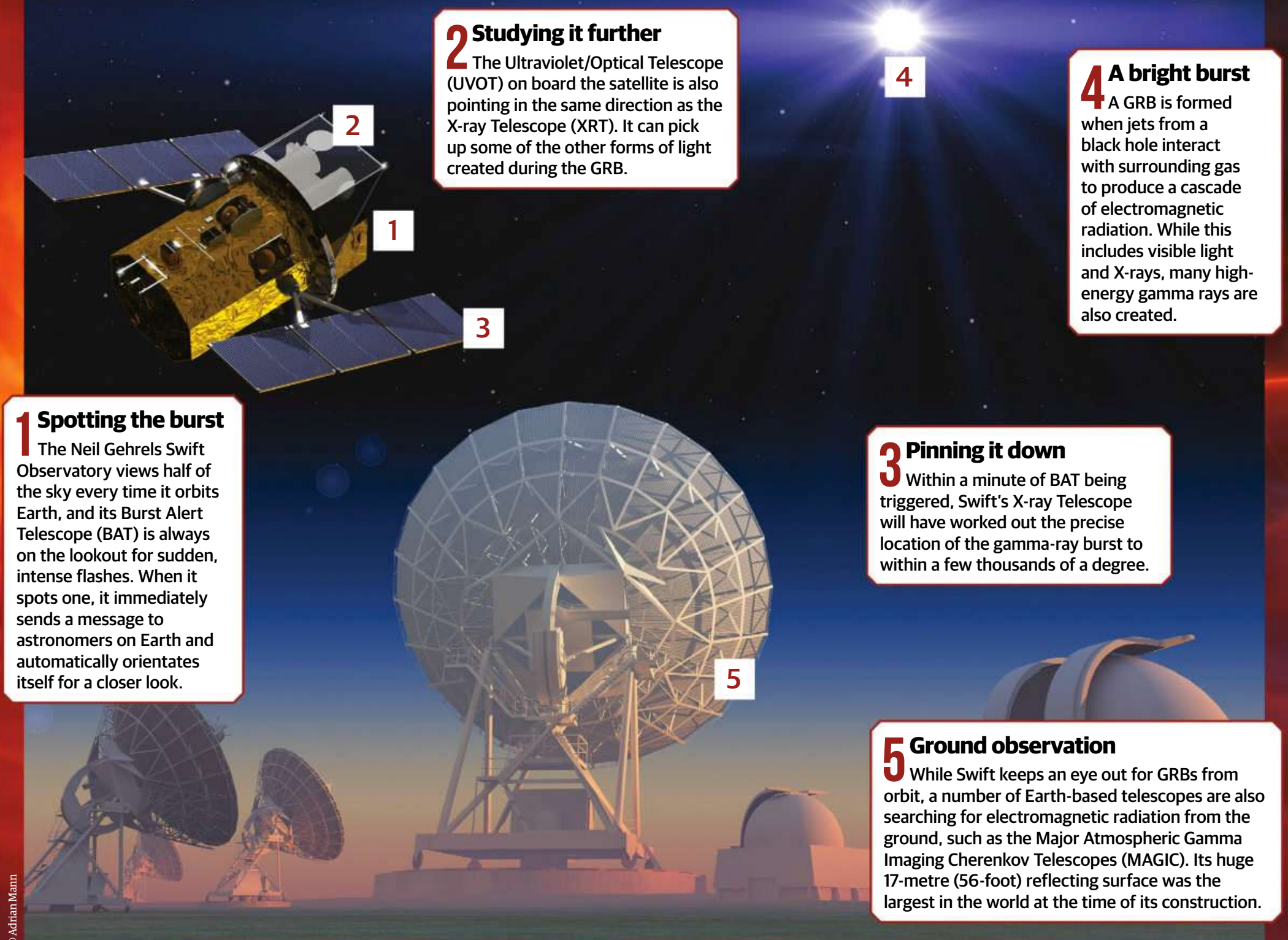
If a neutron star starts to suck in material from the surrounding region, it becomes a very powerful source of X-rays - one of the strongest in our galaxy. There are thought to be 100 million neutron stars in our Milky Way.

PINT-SIZED DANGER: NEUTRON STARS

HOW GAMMA-RAY BURSTS ARE MADE



KEEPING VIGIL OVER VIOLENCE



as the Chandrasekhar limit - and a wave of nuclear fusion will rip apart any white dwarf that ventures too close to it. The resulting Type Ia supernova releases 200 million billion times more energy than the Sun provides to Earth in an entire year. Again, this is more than enough to briefly outshine the galaxy it resides in.

Analysing these explosions in relatively nearby galaxies has allowed astronomers to measure the rate at which the universe has expanded in the past. However, if we are searching for the universe's most violent objects, we have to travel far away from the local universe to the very furthest reaches of the cosmos, where we find quasars. They are the brightest objects in the universe, forming part of a group of objects astronomers refer to as active galactic nuclei (AGN), and get their name from the contraction of 'quasi-stellar'. The luminosity of a single quasar can be up to 100,000-times greater than our entire Milky Way galaxy. They represent the highly energetic cores of some of the earliest, and therefore most distant, galaxies in the universe.

The secret of their power lies in a very similar mechanism to that of GRBs, but on a much larger scale. It is thought that large galaxies form when much smaller galaxies merge together. If each small galaxy had a reasonably big black hole at its centre,

then they will combine in the newly created galaxy to form a supermassive black hole, with a mass greater than a billion Suns.

As this new behemoth starts to devour the surrounding material, the magnetic field around the black hole eventually sprouts two distinct jets of radiation, shooting out from the compact galactic centre like a lighthouse beam. The angle at which we observe this beam determines what we call it. If we see the beam at an angle then that's a quasar. Look straight into the beam and you have yourself a blazar. Finally, if you're looking at right angles to the beam, astronomers know it as a radio galaxy.

The study of AGN is still a relatively new area of astronomy, with observations by the Hubble Space Telescope sending what we knew about them skyrocketing. Yet one of the biggest mysteries surrounding them is why the nucleus of the Milky Way isn't currently anywhere near as active as some of these more distant galaxies. After all, observations suggest our galaxy is centred around a supermassive black hole with a mass equivalent to 4 million Suns.

There is some evidence, however, that the Milky Way hasn't always been so serene. In 2010 the team behind the Fermi Gamma-ray Space Telescope announced the discovery of the so-called Fermi

bubbles - giant gamma-ray structures extending for 30,000 light years on each side of the galactic centre. Their presence points towards a sizeable and rapid eruption of energy close to the Milky Way's black hole several million years ago. In this eruption, gas and other material was driven out at millions of kilometres, or miles, per hour.

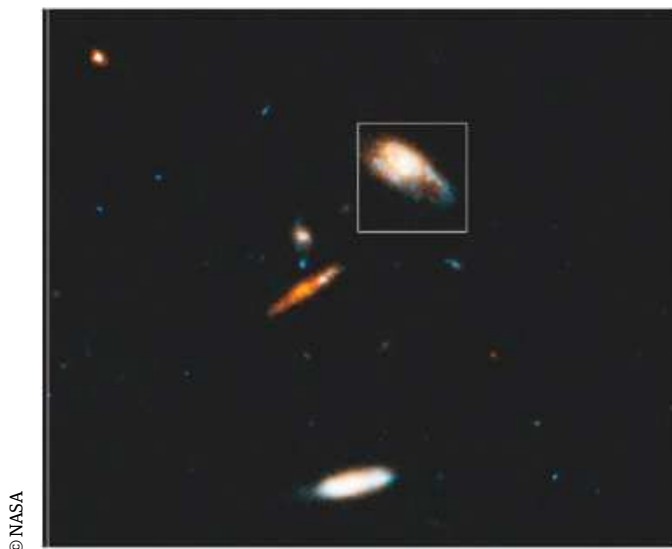
Two explanations are currently on offer for these remarkable structures. The first is that the area close to the galactic centre underwent a period of unprecedented star formation, with many of the stars exploding together as supernovae almost simultaneously. The other is that around the same time our supermassive black hole woke up, and starved from its hibernation went on a feeding frenzy. If it turns out to be the latter, we should be thankful that our black hole effectively goes to sleep for extended periods of time. A healthier appetite would likely flood the Milky Way with intense bursts of lethal radiation, and the rest of the violent universe would be the least of our problems.



Colin Stuart

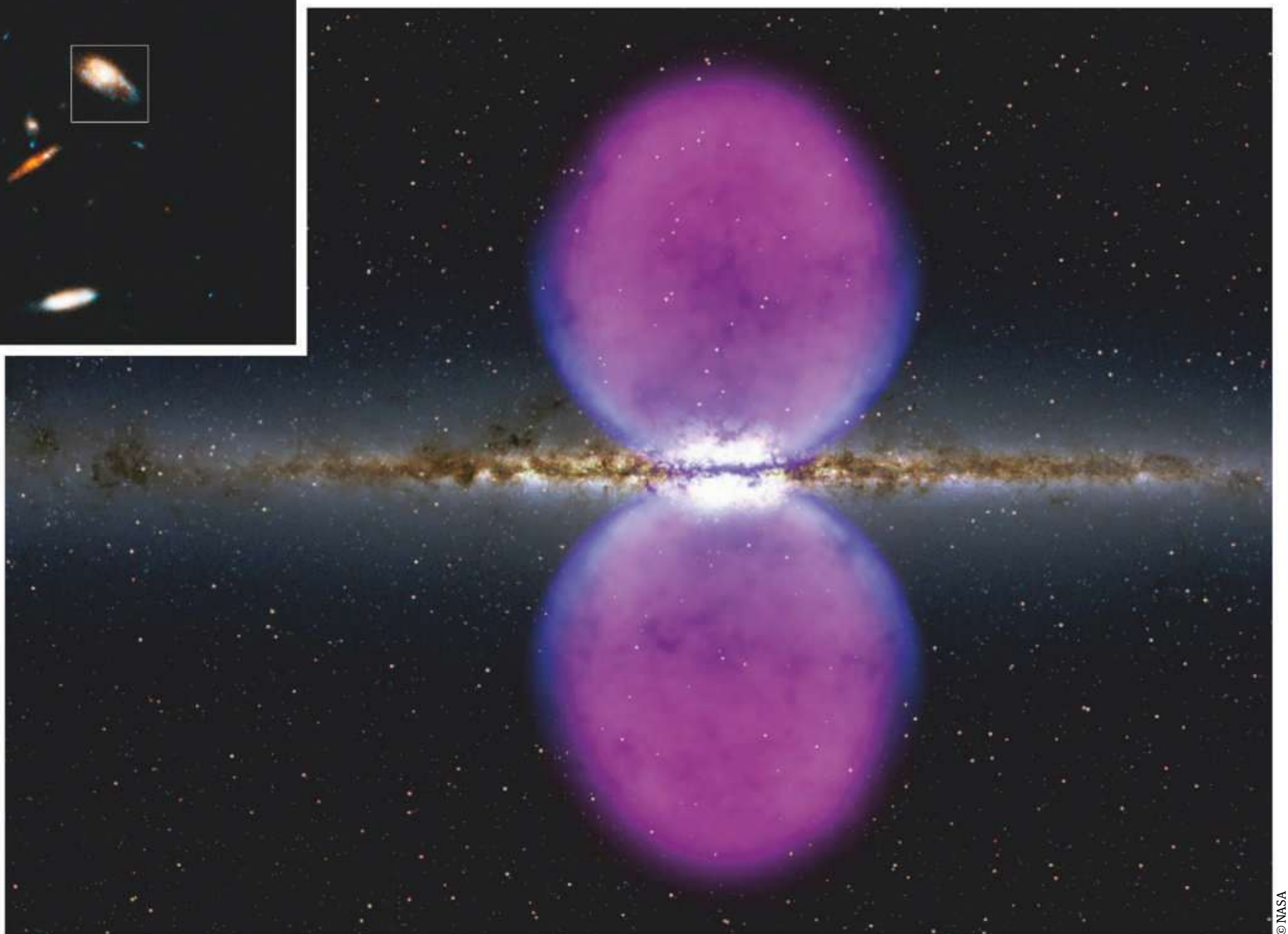
Astronomer & space science writer

Colin holds a degree in astrophysics, has written over 17 books on space and has an asteroid named in his honour: 15347 Colinstuart.



Above: This gamma-ray burst was discovered in a distant galaxy by Hubble in 2013

Right: The gamma-ray bubbles discovered by the Fermi telescope emanating from the centre of the Milky Way



ASTROPHYSICS

What is the minimum amount of material needed to form a star?

Stars across the universe, like our own Sun, are typically born from the catastrophic collapse of a gas cloud. When such a cloud becomes sufficiently massive and dense, it contracts further under its own gravity, making it ever denser and hotter. This contraction eventually stops when densities and temperatures are high enough to ignite thermonuclear fusion of hydrogen into helium at the centre of the protostar. The heat generated from these nuclear reactions then balances the star's gravity, thus creating a stable, long-lived object capable of shining over billions of years.

Forming a star relies on reaching conditions for thermonuclear fusion, specifically forming a plasma in the star's core with temperatures above 10 million degrees Celsius (18 million degree Fahrenheit). Since more massive stars have hotter cores, this translates directly into a minimum mass to sustain fusion. Objects above this mass, such as our Sun, can successfully fuse hydrogen into helium, while objects like a giant planet such as Jupiter cannot. In fact, astrophysicists predict this mass boundary to be eight per cent the mass of our Sun.

To go further, 'failed' stars, or brown dwarfs, that have not reached this threshold lack an internal energy source. They produce little visible light and astronomers had to wait until 1995 to confirm their existence. Our understanding of brown dwarfs has greatly expanded since this initial discovery. For instance, we now know that despite not quite making it as stars, brown dwarfs can host planetary systems.

Dr Martin Rey is a postdoctoral fellow at Lund University, Sweden

Above: Star formation is dependant on the amount of material within a gas cloud

Did you know?

The closest brown dwarf to Earth found so far is Luhman 16A, which lies 6.5 light years away. It's part of a binary pair of brown dwarfs.



SOLAR SYSTEM

What is the interior of an ice giant planet thought to be like?

The ice giants of our Solar System, Uranus and Neptune, are thought to be composed primarily of water throughout most of their interior. The large pressures and temperatures support what is called the 'superionic phase'. Here oxygen ions are arranged in a crystalline lattice and hydrogen ions diffuse freely like in a charged fluid. The outermost third of the planets' interiors are instead dominated by partially dissociated liquid water.

Recent molecular dynamics simulations of the transport properties of water at different planetary conditions suggest new models for the evolution of the ice giants. For instance, Uranus may possess

a frozen superionic core with an anomalously low heat flow, resulting in the observed low luminosity of the planet. Such a 'sluggish' core would be far too viscous to generate a dynamo, which could instead be produced in the upper, fluid third of the planet's interior. Nonetheless, the large electrical conductivity estimated for the superionic phase can play an important role in the shape and evolution of the ice giants' magnetic fields, whose strength and asymmetry are yet to be explained.

Dr Federico Grasselli is a postdoctoral fellow at the Swiss



Federal Institute of Technology Lausanne (EPFL), Switzerland

SPACE EXPLORATION

What is it like to go on a spacewalk?

Outside on a 'spacewalk', we're actually crawling hand over hand using handrails on the outside of the Space Shuttle, space station or the Hubble Space Telescope or whatever we happen to be working on. We're actually not truly walking, but it is an incredible human experience. I think it is the greatest job in the universe to be outside in your own personal 'spaceship' with just a thin visor between you and the enormity of the universe.

You have to have on your body everything that a Space Shuttle has in terms of systems to sustain you there. You need oxygen delivery, carbon dioxide removal, temperature control and protection from the vacuum of space. You need radios, TV cameras, battery power, cooling and lighting; you need a computer to see what is going on with your spacesuit and tools on the front of your suit. You are physically in your own personal spaceship. There's even a little jet backpack on your back that will enable you to fly yourself to safety if you were to float free from the space station. I really think it is a dream to get a chance

to go outside on a spacewalk.

Dr Scott Parazynski is a former NASA astronaut and physician



Right: Parazynski has completed over 47 hours of spacewalking





© NASA

SPACE EXPLORATION

How important are solar cells for the future of space travel?

Solar cells convert the energy of sunlight directly into electricity, making them attractive as a power supply in space. This is because no fuel transport is required and there's no need to deal with the resultant waste.

Today solid-state solar cells are commonly in operation in space. However, energy density - for instance the power conversion efficiency per mass - remains a challenge for the relatively heavy solid-state solar modules. Perovskite and organic solar cells qualify as extremely lightweight and flexible alternative candidates for the future fabrication of solar panels. Due to their outstanding power densities, they will enable much broader uses of solar cells for future missions. Their flexibility will enable new solar module designs since flexible panels can be rolled up or folded.

Apart from an extensive potential to save weight and costs, perovskite and organic solar cells create the possibility for novel space mission designs such as solar-powered deep-space missions and efficient electric propulsion. These are an example of how novel material developments can result in major changes for future space missions.

Peter Müller-Buschbaum is professor of functional materials at the Technical University of Munich, Germany



Left: Utilising the efficiency of solar panels is key to the future of space exploration

Right: NASA's Juno spacecraft gathered radio data of Jupiter's lightning to determine its origin

SOLAR SYSTEM

How is lightning on Jupiter different to that on Earth?

Lightning on Jupiter has been observed by all spacecraft that have encountered the giant planet. NASA's Juno mission has provided the most comprehensive observations using the widest range of techniques. Combining information from the various missions indicates that the typical energies of lightning flashes on Jupiter are not very different from those on Earth. While earlier missions detected lightning deep within the water clouds of Jupiter, where temperatures are mild enough for water to be liquid, Juno discovered that lightning also occurs at much higher altitudes, corresponding to temperatures where pure water would be in the form of ice. Observations of lightning on Earth do show high-altitude lightning, but these are very rare.

The most efficient way to build up and separate electric charges that are essential to making lightning is to have both liquid droplets and ice present. To account for the observed high-altitude lightning on Jupiter, this may be attributable to clouds composed of mixtures of water and ammonia, and at even higher altitudes, pure



© NASA/JPL-Caltech

ammonia. When ammonia mixes with water, it makes a liquid at temperatures below the standard freezing point of water - temperatures encountered at the high altitudes where Juno saw lightning.

The liquid ammonia-water allows the efficient formation of lightning and has no analogue in Earth's upper atmosphere, where ammonia is extremely rare. Hence on Jupiter, in addition to water-caused lightning as on Earth, there is ammonia-caused lightning.



Jonathan Lunine is David C. Duncan professor in physical sciences at Cornell University, New York

EXOPLANETS

Why is looking at an exoplanet's atmosphere up close so important?

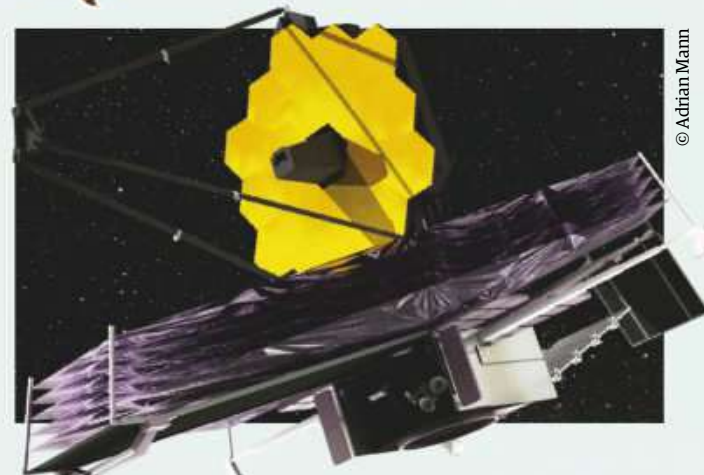
Exoplanet scientists are already characterising the atmospheres of large and hot exoplanets. We've found evidence of lots of clouds, water vapour, methane and other molecules and atoms, as well as evidence of winds. The next stage is pushing the envelope towards smaller and cooler planets.

Large planets have thick atmospheres, which makes them easy to detect and characterise. It also helps if the planet is hot because heat puffs the atmosphere up, making it larger and easier to detect. Small, cool planets, like Earth, have very thin atmospheres, and this is very challenging for our current telescopes. While we're waiting for the next generation of telescopes like the Extremely Large Telescope (ELT) and the James Webb Space Telescope, astronomers are still looking for the most favourable exoplanets for characterisation.

It helps a lot if the exoplanets are relatively nearby - within about 100 light years - transiting and are very close to their parent stars. However, most planets do not transit their parent stars,

and we're interested in more than just close-in planets. Beyond the 2020s, when starlight-blocking technologies like coronagraphs and starshades become more advanced, we will be directly imaging a greater diversity of planets. We will be able to characterise not only exoplanet atmospheres, but also exoplanet surfaces.

Dr Allison Youngblood is a research scientist at the Laboratory for Atmospheric and Space Physics at the University of Colorado Boulder



© Adrian Mann

ASTRONOMY

Why are there different colours in aurorae?

Above: The Sun emits energetic particles at different speeds that can penetrate Earth's atmosphere to various altitudes

The different colours are due to the different atoms and their molecular states when they are excited. The high-altitude emissions come typically from oxygen atoms excited by low-energy electrons, and low-altitude emissions come typically from nitrogen excited by high-energy electrons. The high-energy electrons from space make it to lower altitudes in the atmosphere because they are energetic enough to penetrate deeper and reach denser layers of the atmosphere, where atomic nitrogen exists.

The low-intensity red colours come from oxygen excitation by low-energy electrons reaching roughly 250 kilometres (155 miles) altitude. The most common colour is green, which comes from nitrogen and oxygen excitation by higher energy electrons reaching roughly 100 kilometres (60 miles). The least common, but most intense, is purple, which comes from nitrogen excitation by even higher

energy electrons reaching approximately 80 kilometres (50 miles). They all occur during an intense period of geomagnetic activity, such as magnetic substorms and storms.

These colours appear in layers, or bands, that we call 'aurorae'. This is because they line up along constant magnetic field intensity layers at the equator. You can imagine a bar magnet at the centre of Earth and field lines moving out from the equator into space.

The higher the latitude, the further away the equatorial projection is from Earth. The constant-field equatorial regions lie roughly in a circle of constant distance from Earth, and their ionospheric projections - the aurorae - lie on a constant circle around the magnetic pole. This is how aurorae are arranged.



Vassilis Angelopoulos is the principal investigator of NASA's THEMIS mission

Did you know?

Northern Hemisphere aurorae are called aurora borealis, while in the Southern Hemisphere they are known as aurora australis.



HOW TO TAKE AWARD-WINNING ASTROIMAGES

*BY THE WINNERS OF INSIGHT ASTRONOMY
PHOTOGRAPHER OF THE YEAR*

Astrophotography used to be just for the experts, but not any more

Like the fields and rolling green hills of the countryside on a summer's day, or the ocean bathed in a golden sunset, a starry night sky is so beautiful that it's only natural that people want to photograph it. Similar to any creative hobby, there are different levels of expertise you can aspire to and reach. From dark-sky sites, often far from their homes, experienced astrophotographers use high-tech cameras attached to expensive telescopes to capture multiple images of deep-sky objects, which they then layer - or 'stack' - together and process using sophisticated image-processing software to create portraits of galaxies, clusters and nebulae, some of these rivalling the images that professional observatories were taking a decade ago.

Other astrophotographers, using just entry-level digital SLR cameras on steady tripods, take beautiful images of constellations, meteor showers and the northern lights from their backyard. And today's smartphone cameras are sensitive enough and of high enough quality to let anyone take a lovely photograph of a crescent Moon smiling in the twilight, or a close encounter between two planets in the brightening sky before dawn. Astrophotography is not just for the experts. And like any hobby, the more you practise, the better you get. One day you might even win an award for your photographs.

PHOTOGRAPHING EARTH AND SPACE

From his location in the Southern Hemisphere, Mark Gee captures stunning skylscapes that combine the beauty of Earth and the night sky

When did you begin photographing the sky?

It wasn't until I moved to Wellington, New Zealand, over a decade ago that I discovered astrophotography. I remember going to a remote seaside village and seeing the galactic centre of the Milky Way for the first time. I could hardly believe it was real, and I spent the rest of that night looking up at the sky being totally blown away by how many stars I could see. I decided that I had to learn how to photograph what I saw that night.

Can you tell us about your prize-winning photo?

I photographed it in the same area where I first saw the Milky Way. It's a very dark, remote location on the southeastern cape of the North Island, and my plan was to shoot a time-lapse looking straight up at the lighthouse. When I went to check on my time-lapse, the Milky Way was low in the sky, seemingly projecting out from the guiding light of the lighthouse. I ran as fast as I could to get my equipment and shot a 360-degree panorama using a GigaPan robotic panohead. Guiding Light to the Stars is a 220-degree crop of that panorama.

What is your go-to equipment?

I shoot 90 per cent of my images with a Canon 6D DSLR and a Zeiss 15mm f/2.8 lens on my tripod, and a lot of the time that's all I will head out with. I also do a lot of time-lapses and use a Syrp Genie motion control unit on a slider to get the motion.

Do you have any special techniques?

These days an entry-level DSLR camera and wide-angle lens on a tripod will allow you to get some impressive images. You just need to set a long exposure, with your aperture wide open and a relatively high ISO value. The real trick to taking a stunning skyscape involves getting a good composition and marrying the landscape to the sky. I always plan my shoots and compositions, making sure I visit the location in the daytime before attempting to photograph it at night.



Mark Gee
IAPY 2013
Earth and
Space winner:

Guiding Light to the Stars

CAPTURING GALAXIES

Michael van Doorn takes beautiful portraits of galaxies far, far beyond the Milky Way

◆
**Michael
van
Doorn**
**IAPY 2015
Galaxies
winner:**
M33 Core

What excites you about astrophotography?

At a very early age I was already interested in just about everything around me, especially astronomy, and started to read all kinds of books about it. Later in life I started with photography and practised almost exclusively macro photography, because capturing things the human eye can't see on photo was an intriguing aspect of the hobby. I still wonder why it took so long to combine the two interests: photography and astronomy. And so in 2012 a new hobby was born.

Have you had many photographs published?

No - my first and only published photograph was the image that won the Insight Astronomy Photographer of the Year competition in 2015.

Michael's tips for capturing galaxies

Use a camera - a DSLR or a more advanced CCD camera - attached to a telescope

Make the most of nights with clear, dark and steady skies

Use image-processing software to 'stack' and complete your images

Make sure you have lots of memory available on your computer

What a way to start! Tell us about it...

Some friends pushed me a little to enter the competition, but I never expected to win. Although it was great to win the award, I don't have a great hunger for winning competitions, so I have not entered any others. The image was a high-resolution image of the neighbouring spiral galaxy M33. The data for this image was shot from my home in the Netherlands, but not very long after this image was taken, I started imaging from a remote observatory in the south of Spain with another enthusiast. The data coming from this observatory is of a much higher standard, making it possible to image much more difficult objects such as dark nebulae and tidal tails from galaxies.

Can you tell us about the equipment you use?

When imaging in the Netherlands, where clear nights are rare, my favourite astrophotography equipment was an 11-inch (280mm) SCT reflector with a Hyperstar lens installed. This makes the system really fast: at 560mm f/2.0 the photons came in quick - about 15-times quicker than ordinary systems like refractors. With this speed I could image a lot of objects and learn the techniques quickly.

With the whole sky to photograph, what's the special appeal of photographing galaxies?

Astrophotography requires a substantial commitment, and experience comes only at the expense of a lot of sleep. But nothing can beat the fulfilment of seeing a picture come alive after hours and hours of imaging under a beautiful, starry night sky. Think about it: the photons from those galaxies travelled for millions of years before finally reaching my camera lens, creating an image of a beautiful object.

How do you maximise your chances of taking good astrophotographs?

It is all about planning. Get the maximum out of those rare clear nights when there is no Moon by shooting your luminance and RGB frames. When the Moon is present, take your narrowband frames. I also shoot two hours' worth of data per object on a clear night, using only the hours when the object is near the zenith, before moving on to the next object when it comes closer to the zenith. This way I am taking images of the best possible quality.

Which object would you like to photograph but haven't yet?

For some reason I've never imaged M1, despite it being one of my favourite objects. But now that I'm imaging from a remote observatory with over 250 clear nights a year, I think I will succeed this time.

CHASING THE NORTHERN LIGHTS

James Woodend takes spectacular shots of the aurora borealis. How does he do it?

What's the background story behind your award-winning photograph?

The image was taken at Jökulsárlón, South Iceland, at 01:42 on 9 January 2014. I had visited the ice lagoon at Jökulsárlón on several occasions - I knew exactly the location to take a good reflection photograph of an aurora, but the conditions had always prevented me from getting the image I wanted. During January 2014, the lagoon was free from a covering of surface ice - rare in winter - and with no wind to ripple the surface, all I needed was a touch of moonlight, clear skies and an aurora to get the shot. The night in question was cloudy, but there was a sudden break of clear sky just after 01:00, and above was a spectacular aurora dancing across the sky. I got my shot.

You were in the right place at the right time.

What equipment do you carry with you?

I tend to upgrade and change my equipment on a regular basis as and when the noise level of cameras improves. One bit of equipment that has served me well over many years is my carbon-fibre Gitzo tripod. It's solid as a rock on a windy night - they are expensive but worth the outlay.



James Woodend

**IAPY 2014
Earth and
Space winner:**

Aurora Over a
Glacier Lagoon



© James Woodend

Everyone loves a beautiful display of aurorae.

Why were you drawn to the northern lights?

If you view the Moon, planets, stars, galaxies and so on then you are an observer. If you are present when a large, energetic aurora kicks off directly overhead, then it's as if you are somehow a participant.

What would you say are the essentials for photographing aurorae?

A sturdy tripod, a reasonably noise-free digital camera and a fast wide-angle lens. Aurorae tend

to occur towards the polar regions, so you need to be as far north or south as you can possibly get, and as far away from light pollution as possible. Winter is a good time to image aurorae because you have long, dark nights. I have photographed for over seven hours at night with temperatures below -35 degrees Celsius (-31 degrees Fahrenheit). I found the camera had no issues, but there were problems. Camera batteries do not last long in the cold, so several fully charged back-up batteries tucked inside a warm coat pocket are essential.

“If you are present when a large, energetic aurora kicks off, it's as if you are a participant” **James Woodend**

“I DIDN'T HAVE TIME TO MOVE. I HAD TO TAKE THE PICTURE FROM WHERE I STOOD”



Jamen Percy

**IAPY 2015
Aurorae
winner:**
Silk Skies



© Jamen Percy

Overall winner of Insight Astronomy Photographer of the Year's Aurorae category in 2015, Percy headed over to Abisko National Park in Lapland, Sweden, to take his prize-winning shot. Using a Canon EOS 5D Mark III camera with a 24mm f/1.4 lens at ISO 2,000 and using a four-second exposure, he recalls the moment he captured the Swedish Silk Skies: “After waiting many hours on top of the mountain for the aurora, I finally gave up and decided to call it a night. I packed up my gear and began to walk back. As I stumbled down the hill, I noticed the snow reflecting a green glow - you can see my footprints on the left. I quickly turned around and looked up to see this.”

SHOOTING THE SOLAR SYSTEM

Damian Peach is one of the most successful and respected astrophotographers in the world, specialising in imaging the planets

What got you started in astrophotography?

It was seeing images published in magazines during the mid 1990s, especially the planetary work of Don Parker. Don Parker was a pioneering astrophotographer who died in 2015. Many people think that his photographs of the planets, taken in the early days of CCDs and image processing, revolutionised astrophotography.

Tell us about the first image you had published and how it differs from the images you're taking now.

I don't actually recall the very first photo I had published. However, I can remember the first photo I had featured on the *Sky At Night* TV programme - it was an image of Saturn, taken in October 1999, and it featured in the show the following month. Compared to the images taken today it is of much poorer resolution, but for the time it was very good.

Can you tell us a little bit about your favourite or most used piece of equipment?

I think it would have to be my first C14 telescope. I've had so many great views and images with this scope, and even today it continues to perform. Portraits of Saturn, Jupiter and Mars are well respected and admired around the world.

Damian Peach

IAPY 2011 Our Solar System winner:

Jupiter with Io and Ganymede



© Damian Peach

What's the special appeal of photographing Solar System objects for you and what is your favourite object to image?

Their dynamic nature. They have ever-changing weather, which makes them fascinating objects to study in the long term. My favourite has to be Jupiter. I've had so many incredible views of it through the years, and even today its weather keeps us guessing as to what will happen next.

It's very tempting for some beginners to look at your gorgeous photos - showing the

caramel cloud bands of Jupiter and Saturn's shining rings - and think to themselves: "I'll never be as good as Damian... I shouldn't even bother trying!" What advice would you give to them?

Astrophotography should never really be viewed as a competition. Enjoying it is far more important, and although when starting out things can seem daunting, with time and practice it's possible for anyone to start achieving good results. Astrophotography is all about practice and commitment.

SNAPPING STAR CLUSTERS

Beneath the beautiful southern constellations, Ignacio Diaz Bobillo specialises in imaging distant nebulae and glittering star clusters



Ignacio Diaz Bobillo

IAPY 2015 Stars and Nebulae winner:

The Magnificent Omega Centauri

Has astrophotography always interested you?

I became interested in my early youth. I started with visual astronomy, using a small Newtonian telescope, but was soon intrigued by the possibilities of astrophotography. I started with wide-field imaging using a telephoto lens. These were still the days of film photography, and I also had to venture into chemical developing. It was fun.

What do you enjoy most about photographing distant nebulae and clusters of stars?

I live in the Southern Hemisphere, so I enjoy the better views of our Milky Way. How could I not try to image those beautiful, extended dusty objects, sprinkled with tens of thousands of colourful stars?

There are so many different objects to photograph, and it's enough to keep you busy for a long time.

With such a wealth of objects available in the Southern Hemisphere, what's your favourite?

I don't really have a favourite. All are interesting and challenging to image in their own right. Each new Moon I carefully plan ahead and choose those objects that are best positioned in the sky.

Can you give any advice for beginners?

Keep it simple with wide-field astrophotography or with a small, guided refractor. Then move slowly up to the next level of difficulty, but only when you master your current level. Pay as much attention to acquisition as data processing; they are both critical.



© Ignacio Diaz Bobillo

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STARGAZER

ESSENTIAL GUIDES AND ADVICE FOR AMATEUR ASTRONOMERS

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Red light friendly

In order to preserve your night vision, you should read our observing guide under red light

What's in the sky?

10 OCT



The Southern Taurids reach their peak of five meteors per hour

11 OCT



The Delta Aurigids reach their peak of two meteors per hour

14 OCT



Mars reaches opposition in Pisces

17 OCT



Dwarf planet Eris is at opposition from the Sun in Cetus



18 OCT



The Epsilon Geminids reach their peak of around three meteors per hour

23 OCT



The Moon and Saturn make a close approach within 2°34' of each other in Sagittarius

23 OCT



Asteroid 11 Parthenope reaches opposition in Pisces

24 OCT



The Leonis Minorids reach their peak of two meteors per hour

27 OCT



Asteroid 471 Papagena reaches opposition in Cetus

27 OCT



Open star cluster NGC 884 is well placed for observation in Perseus

29 OCT



The Moon and Mars make a close approach within 2°42' of each other in Cetus and Pisces



Jargon buster

Conjunction

A conjunction is an alignment of objects at the same celestial longitude. The conjunction of the Moon and the planets is determined with reference to the Sun. A planet is in conjunction with the Sun when it and Earth are aligned on opposite sides of the Sun.

Right Ascension (RA)

Right Ascension is to the sky what longitude is to the surface of the Earth, corresponding to east and west directions. It is measured in hours, minutes and seconds since, as the Earth rotates on its axis, we see different parts of the sky throughout the night.

Declination (Dec)

This tells you how high an object will rise in the sky. Like Earth's latitude, Dec measures north and south. It's measured in degrees, arcminutes and arcseconds. There are 60 arcseconds in an arcminute and there are 60 arcminutes in a degree.

Magnitude

An object's magnitude tells you how bright it appears from Earth. In astronomy, magnitudes are represented on a numbered scale. The lower the number, the brighter the object. So, a magnitude of -1 is brighter than an object with a magnitude of +2.

Opposition

When a celestial body is in line with the Earth and Sun. During opposition, an object is visible for the whole night, rising at sunset and setting at sunrise. At this point in its orbit, the celestial object is closest to Earth, making it appear bigger and brighter.

Greatest elongation

When the inner planets, Mercury and Venus, are at their maximum distance from the Sun. During greatest elongation, the inner planets can be observed as evening stars at greatest eastern elongations and as morning stars during western elongations.

1969 to 1979 (all modules)

Owners' Workshop Mar

**14
OCT**



The Moon and Venus make a close approach, passing within 4°02' of each other in Leo

**14
OCT**



The Triangulum Galaxy (M33) is well placed for observation in Triangulum

**21
OCT**



The Orionids reach their peak of around 15 meteors per hour

**22
OCT**



The Moon and Jupiter make a close approach, passing within 2°00' of each other in Sagittarius



© ESO

**26
OCT**



Open star cluster NGC 869 is well placed for observation in Perseus

**31
OCT**



Uranus reaches opposition in Aries

**1
NOV**



Asteroid 8 Flora reaches opposition in Cetus



Naked eye



Binoculars



Small telescope

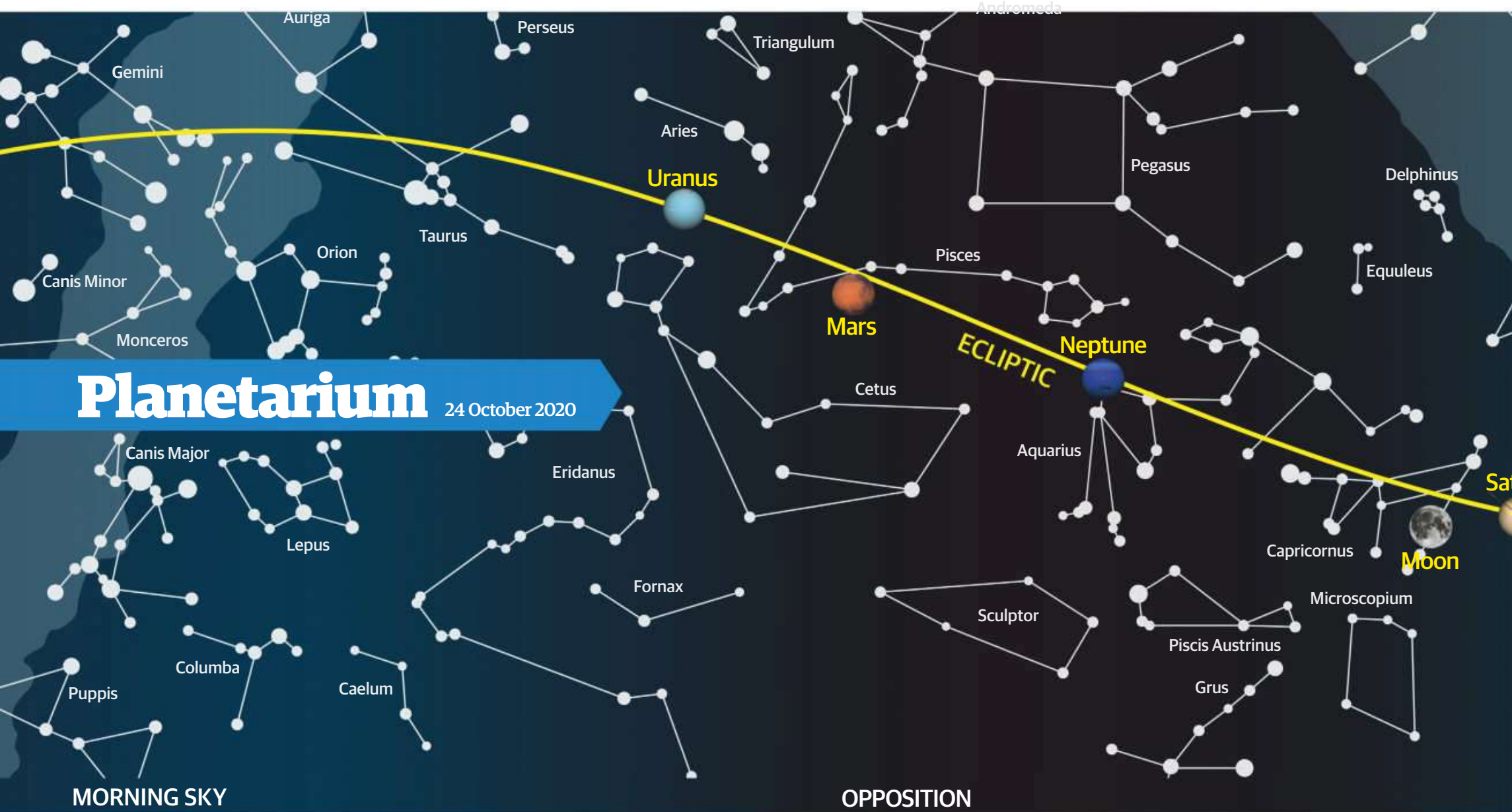


Medium telescope



Large telescope



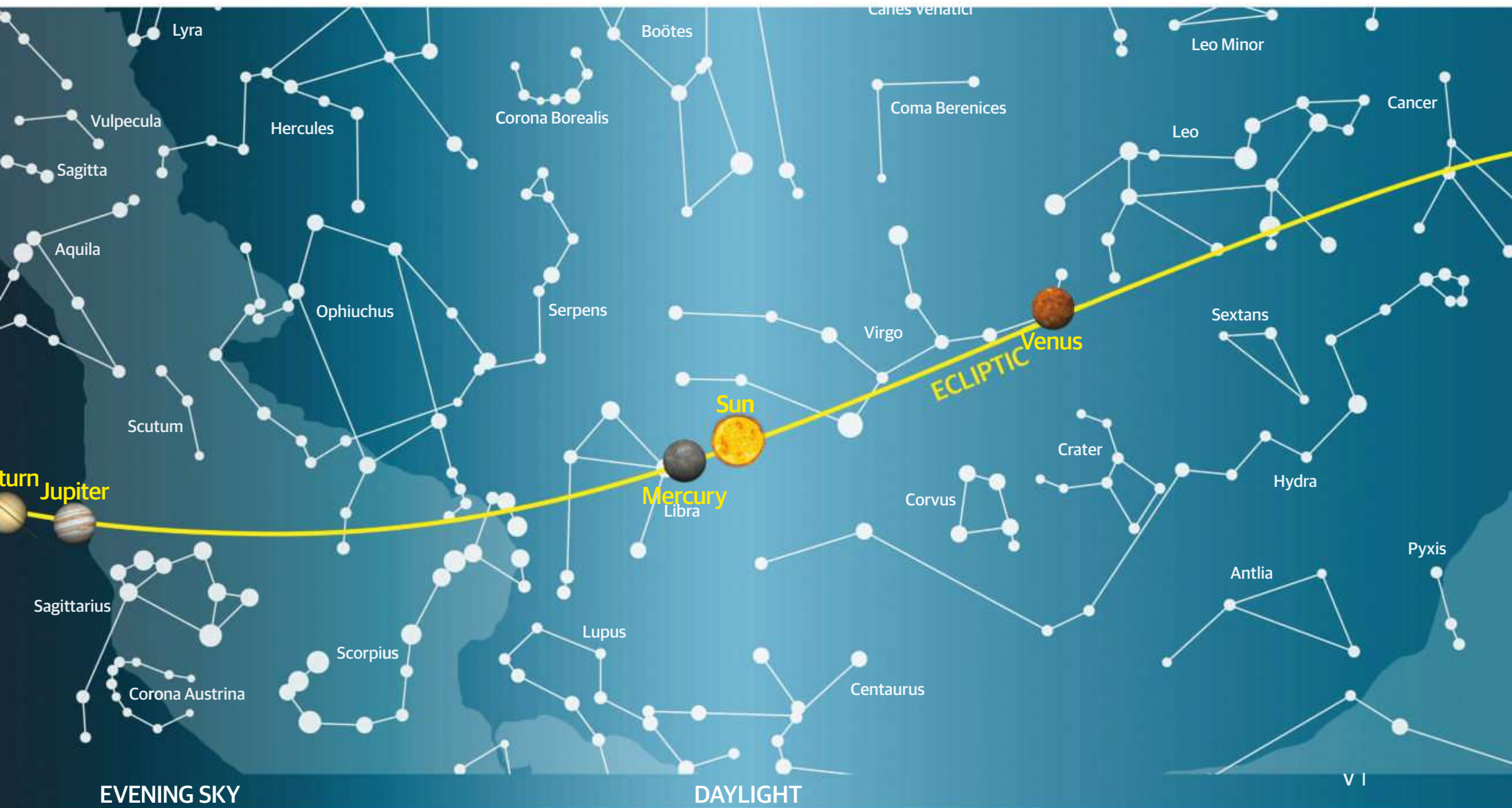


Moon calendar

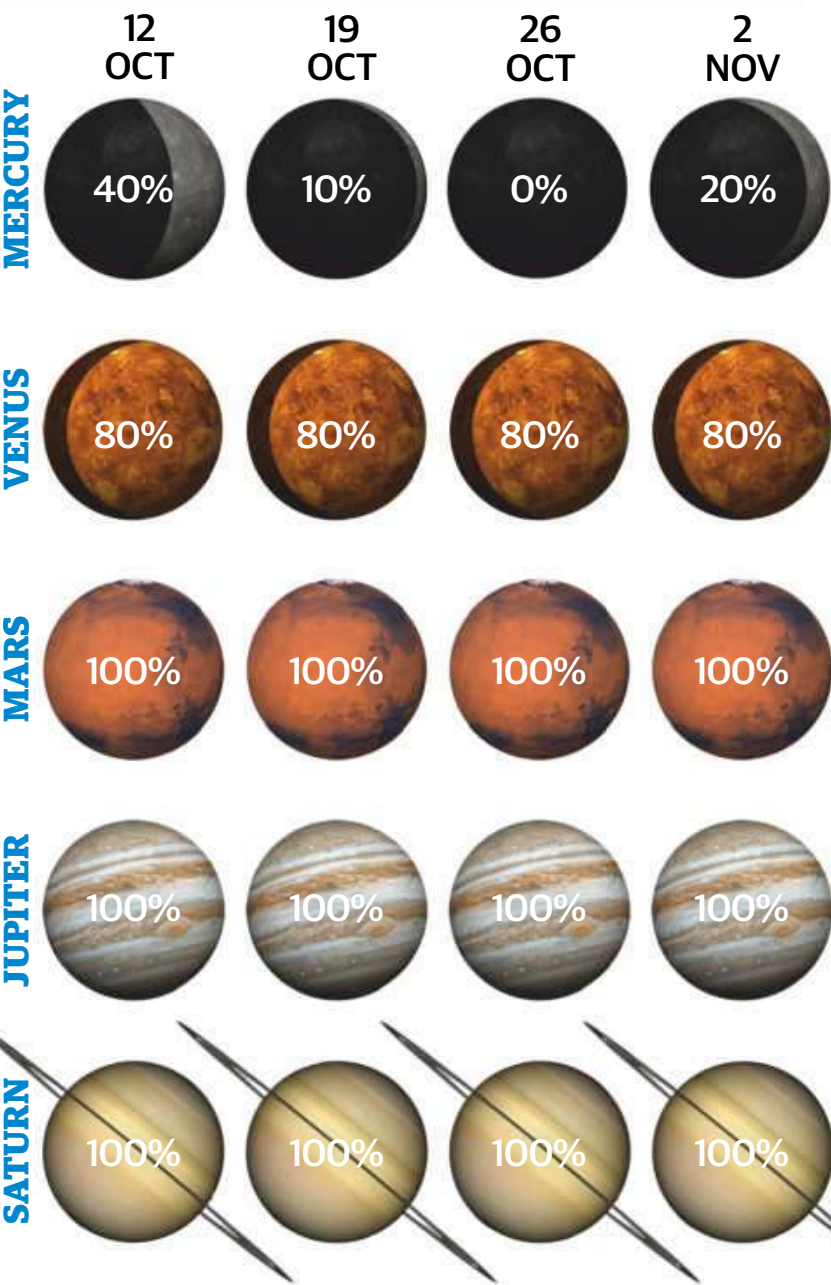
* The Moon does not pass the meridian on 31 October

8 OCT

All figures are given for 00h at midnight (local times for London, UK)



Illumination percentage



Planet positions

All rise and set times are given in BST/GMT

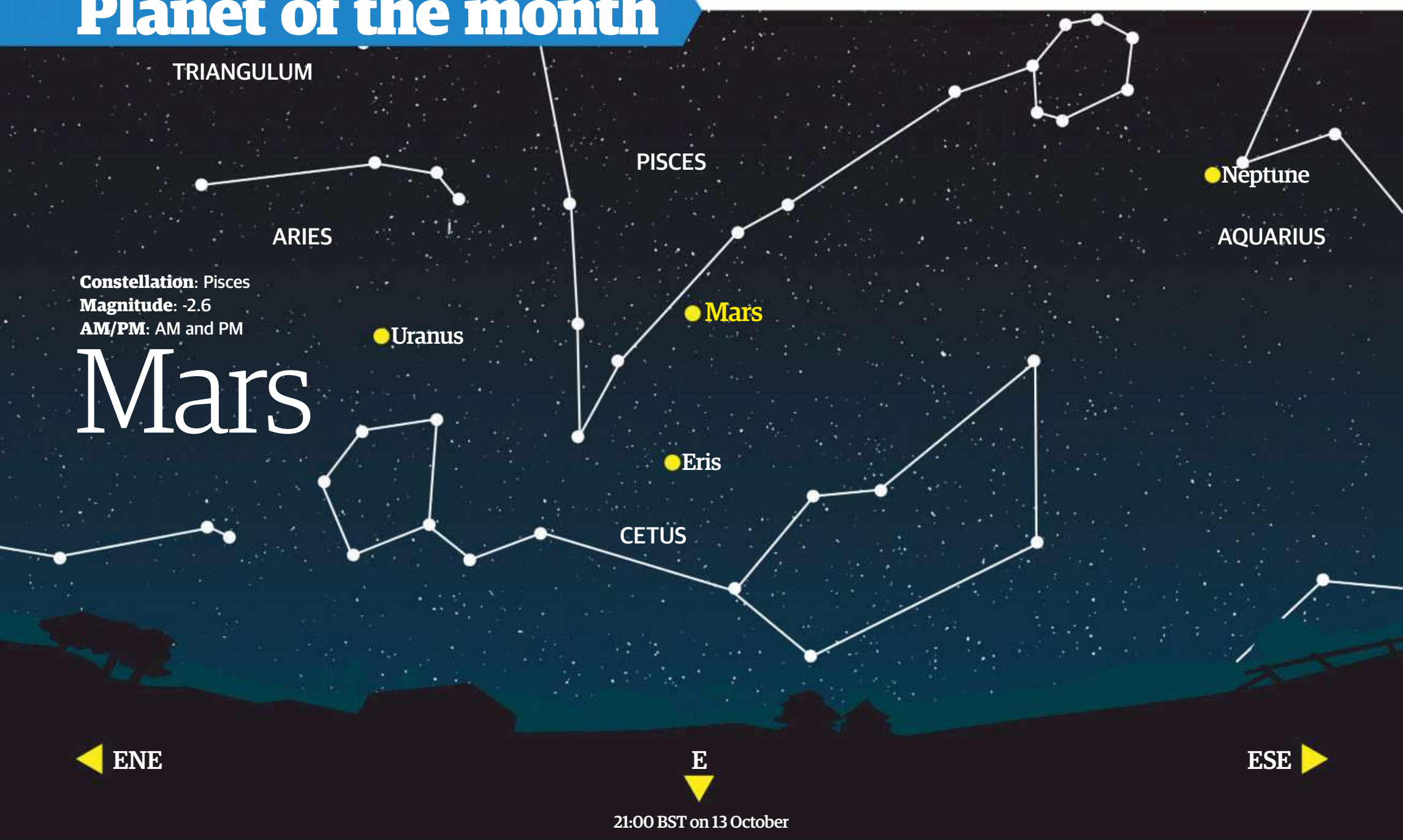
	Date	RA	Dec	Constellation	Mag	Rise	Set
MERCURY	10 OCT	14h 27m 43s	-18° 09' 41"	Libra	+0.2	09:44	18:37
	17 OCT	14h 29m 31s	-17° 58' 53"	Libra	+1.2	09:17	18:13
	24 OCT	14h 07m 45s	-14° 30' 54"	Virgo	+4.9	08:08	17:44
	31 OCT	13h 41m 12s	-09° 37' 59"	Virgo	+2.1	05:47	16:16
	4 NOV	13h 37m 32s	-08° 16' 59"	Virgo	+0.3	05:21	16:04
VENUS	10 OCT	10h 40m 09s	+09° 15' 15"	Leo	-4.1	03:32	17:15
	17 OCT	11h 11m 42s	+06° 23' 14"	Leo	-4.0	03:51	17:04
	24 OCT	11h 43m 07s	+03° 19' 53"	Virgo	-4.0	04:11	16:52
	31 OCT	12h 14m 32s	+00° 09' 00"	Virgo	-4.0	03:31	15:40
	4 NOV	12h 32m 33s	-01° 41' 56"	Virgo	-4.0	03:42	15:32
MARS	10 OCT	01h 26m 27s	+05° 34' 54"	Pisces	-2.6	18:36	07:43
	17 OCT	01h 17m 30s	+05° 10' 02"	Pisces	-2.6	18:01	07:05
	24 OCT	01h 09m 17s	+04° 51' 22"	Pisces	-2.4	17:27	06:27
	31 OCT	01h 02m 43s	+04° 42' 56"	Pisces	-2.2	15:54	04:53
	4 NOV	00h 59m 56s	+04° 43' 32"	Pisces	-2.0	15:35	04:34
JUPITER	10 OCT	19h 19m 25s	-22° 37' 22"	Sagittarius	-2.3	15:03	23:00
	17 OCT	19h 22m 14s	-22° 32' 11"	Sagittarius	-2.3	14:38	22:36
	24 OCT	19h 25m 36s	-22° 25' 40"	Sagittarius	-2.2	14:13	22:12
	31 OCT	19h 29m 29s	-22° 17' 47"	Sagittarius	-2.2	12:48	20:49
	4 NOV	19h 31m 55s	-22° 12' 40"	Sagittarius	-2.2	12:35	20:37
SATURN	10 OCT	19h 48m 38s	-21° 25' 05"	Sagittarius	+0.5	15:24	23:37
	17 OCT	19h 49m 21s	-21° 23' 35"	Sagittarius	+0.5	14:57	23:10
	24 OCT	19h 50m 23s	-21° 21' 12"	Sagittarius	+0.6	14:31	22:44
	31 OCT	19h 51m 45s	-21° 17' 56"	Sagittarius	+0.6	13:04	21:18
	4 NOV	19h 52m 40s	-21° 15' 40"	Sagittarius	+0.6	12:49	21:04



This month's planets

Mars hits opposition with far-flung ice giant Uranus, while Jupiter fades as we roll into November

Planet of the month



For the first time since 2018, the Red Planet, Mars, reaches opposition, gracing our skies as a shining red orb from dusk until dawn. Other than Venus and the Moon, Mars will be the brightest object in the night sky. It's also handily placed, reaching about 45 degrees above the horizon at 02:00 on opposition night of 13 October.

Every time Mars is at opposition, an email hoax does the rounds claiming that Mars will appear as large as the full Moon in the sky. This is not true - you won't even be able to make out the disc shape of Mars with the unaided eye. However, the view through a telescope of Mars' 22.6-arcsecond-diameter disc will appear equivalent to the full Moon when seen without telescopic aid.

Even a four-inch-aperture telescope will be able to show you the dark markings of the most prominent surface features, such as the V-shaped Syrtis Major. It helps if you can use astronomical filters, particularly red or orange, to enhance the contrast of the dark features.

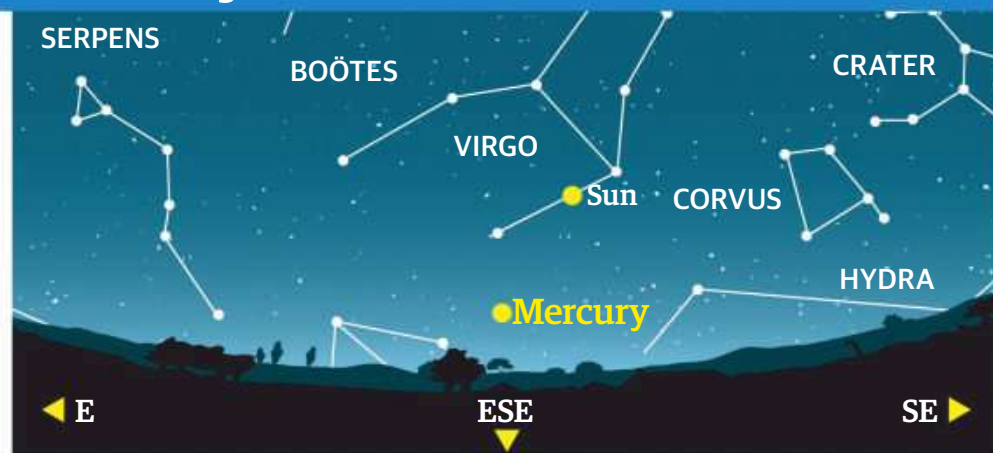
Mars remains very prominent in the night sky for the entirety of October, having faded only to

magnitude -2.2 by the end of the month. It will also be visible all night, so there's no need to panic about missing out on the Red Planet because of clouds - take your time, and wait for clear skies.

While viewing Mars this month you can think of NASA's Perseverance Rover, which is currently on its way to a landing site in the Jezero crater to unlock more of the planet's secrets.

"MARS REMAINS VERY PROMINENT IN THE NIGHT SKY FOR THE ENTIRETY OF OCTOBER, HAVING FADED ONLY TO -2.2 BY THE END OF THE MONTH"

Mercury 21:30 BST on 20 October



Constellation: Libra

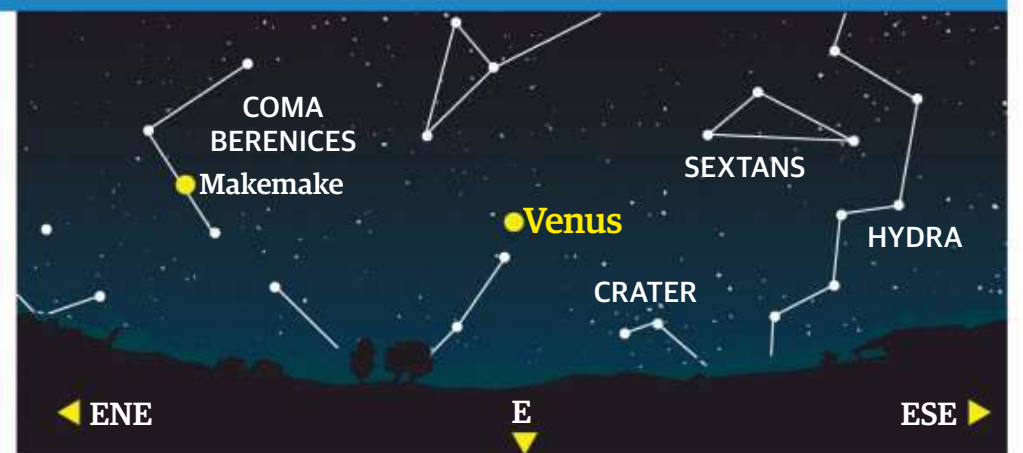
Magnitude: +1.5

AM/PM: PM

The innermost planet spends October not really visible from the Northern Hemisphere, although

observers in the Southern Hemisphere will have a better view, at least until 25 October when Mercury moves close to the Sun from our point of view and is rendered invisible by the glare.

Venus 05:30 BST on 23 October



Constellation: Leo

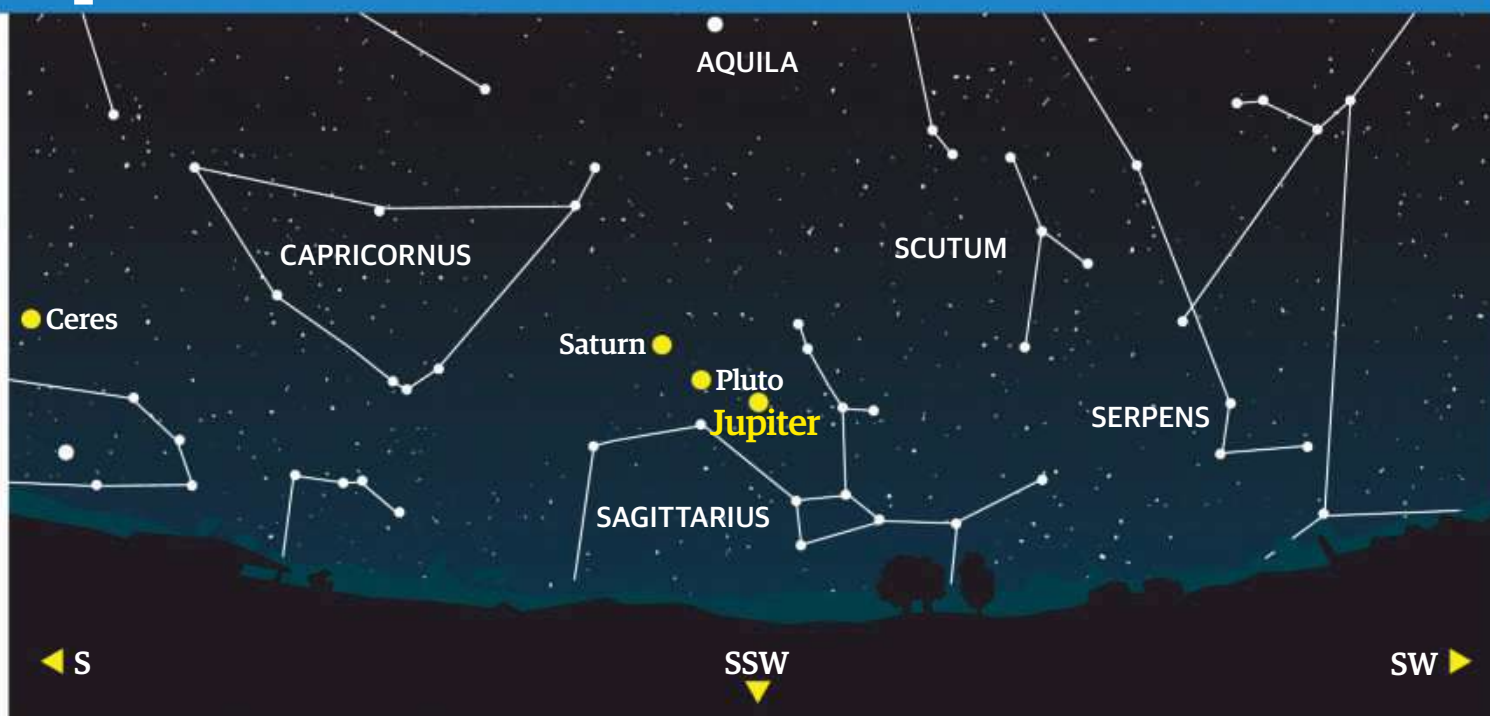
Magnitude: -4.0

AM/PM: AM

This autumn Venus shines incandescent in the eastern sky before dawn, the brightest 'star'

visible. During October it rises three hours before the Sun, and although this is reduced to two hours in November, it is still stunningly brighter than anything else in the night sky bar the Moon.

Jupiter 20:30 BST on 20 October



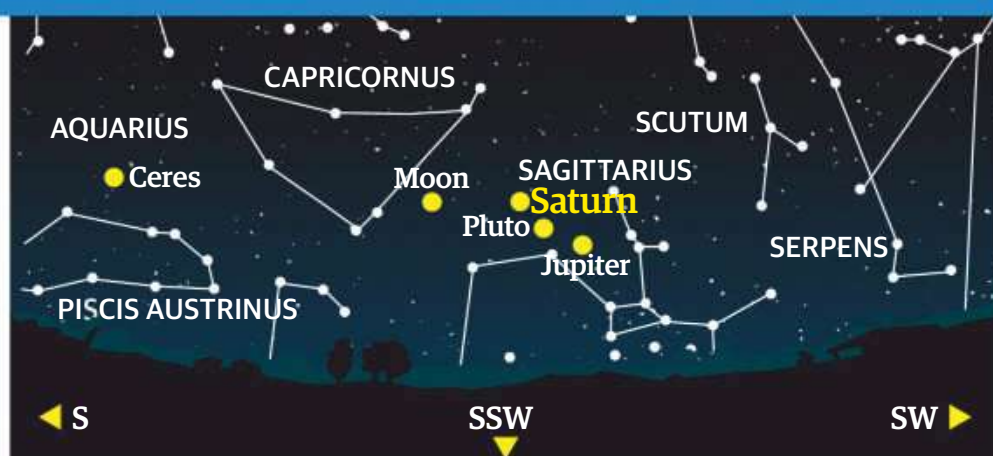
Constellation: Sagittarius

Magnitude: -2.5

AM/PM: PM

After blazing as a bright blue-white ball all throughout the summer, Jupiter, the red-banded king of the Solar System, is visible only for a few hours in the evening sky before setting at around 22.45 in the middle of October - and even earlier at 21:00 by the beginning of November. Even so, it shines just a notch fainter than Mars at its best, and even a small telescope should show its characteristic atmospheric bands and its four largest moons, Io, Europa, Ganymede and Callisto, orbiting around it as tiny points of light on either side of the gas giant.

Saturn 20:30 BST on 23 October



Constellation: Sagittarius

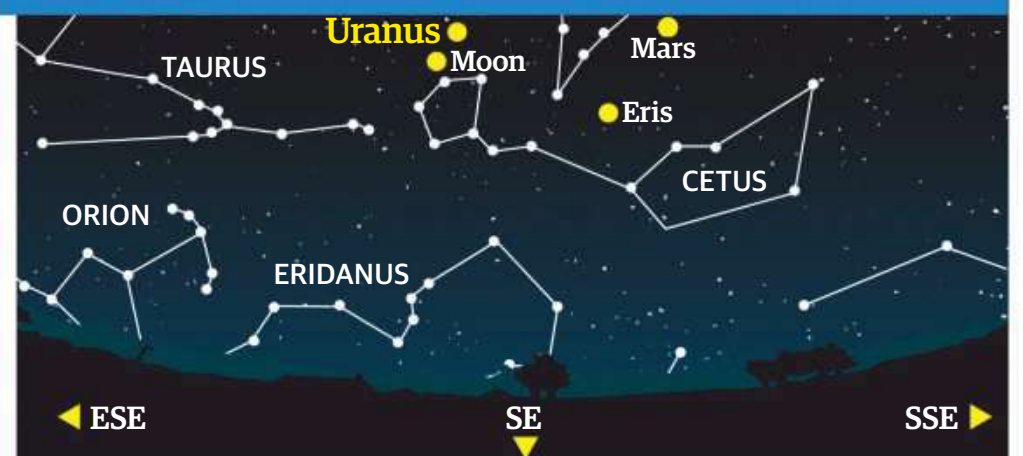
Magnitude: +0.4

AM/PM: PM

The ringed planet Saturn is suffering a similar fate to Jupiter, sinking below the horizon about 45

minutes after it. Being low down in the sky, our turbulent, dusty atmosphere acts to obscure many of the planet's details, but a telescope of four inches in aperture or greater should still show Saturn's rings.

Uranus 21:00 GMT on 31 October



Constellation: Aquarius

Magnitude: +5.7

AM/PM: AM and PM

Mars isn't the only planet to come to opposition in October - ice giant Uranus is also at its best on the 31st.

Because of its great distance from us, the seventh planet from the Sun is still relatively faint in the night sky - although it's theoretically visible to the naked eye under the darkest skies.



STARGAZER

Top tip!

Copernicus looks the most impressive just after first quarter or just after last quarter. At full Moon it is just a bright spot.

Moon tour

Copernicus

This month we bow down before the 'Monarch of The Moon'

Ask any Moon observer to name their favourite lunar crater and chances are most will nominate the same feature: Copernicus. Copernicus has a nickname - the Monarch of the Moon - and if you've only ever seen photographs of the crater but never seen it with your own eyes, you would be forgiven for thinking that sounds a bit pompous. But it is entirely justified.

Just as every amateur astronomer remembers their first view of Saturn and its rings through a telescope, or their first display of the northern lights, they never forget the first time they see Copernicus through a telescope. In fact, the crater is one of the first things a beginner will see through a pair of humble binoculars because it stands out so starkly on the Moon, even when viewed under 10x magnification through a shaking pair of binoculars on a chilly October night.

Copernicus was formed in fire and fury. Some time between 800 million and 1 billion years ago the Moon collided with a large asteroid. The explosion caused by the impact blasted an enormous hole out of the area of the Moon we now know as Oceanus Procellarum, the Ocean of Storms. The gaping pit left behind was

almost four kilometres (2.5 miles) deep and more than 93 kilometres (58 miles) wide, which means its opposite walls are as far apart as London and Clacton-on-Sea.

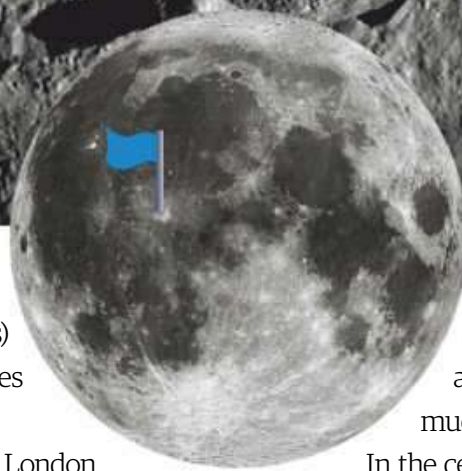
The impact didn't just excavate a hole; it sent an enormous debris cloud of dust and rocks billowing up into the sky and across the lunar landscape. Some of that material fell back down to the Moon, spraying across it and leaving bright rays of ejecta splashed on the landscape. These 'debris rays' are so bright and so long - the longest stretches for over 800 kilometres (497 miles), the distance between London and John o' Groats - that they can even be seen with the naked eye when the Moon is full, looking like white chalk lines drawn on the Moon's grey-blue face.

The crater itself lies just south of Montes Carpatius, the Carpathian Mountains, a short range of mountains on the southern shore of Mare Imbrium. Copernicus is roughly circular in shape and its walls are terraced on all sides, with a wide shelf dropped down on the western side and landslides in several places. The

crater's floor is quite flat, a plain of ancient lava pocked here and there with much smaller, much younger craterlets.

In the centre of the crater a trio of mountains protrude from the lava plain.

So how can you see this celebrity crater this coming month, and when will it look its best? Copernicus is fully illuminated at the start of our observing period, when the Moon will be a waning crescent glowing in the east before dawn. With the Sun's light slanting in at a low angle from the west the crater will stand out starkly from its surroundings and will be an impressive sight in a telescope. Magnified 100x or more it looks like an empty eye socket staring back at you from across space. However, it will only be visible until the 13th, when the terminator will sweep over it and plunge it into darkness. The crater will then be hidden from view until 27 October, when it emerges into the sunlight again. As the nights pass the crater's appearance will change, its sharp outline and interior details blurring away as the Sun climbs higher in the lunar sky.



Naked eye & binocular targets

Enjoy some of the Summer Triangle's delights before it disappears from view for another year

1 Deneb (Alpha Cygni)

The brightest star in Cygnus, the Swan, blue-white Deneb is the 19th-brightest star in the sky. Around 2,600 light years away, it is an enormous supergiant star which would swallow up Mars' orbit if put in our Sun's place. It is more than 200,000-times more luminous than the Sun.

3 The Great Rift

Look at Cygnus under a dark sky and you will see a dark lane running down its left, almost as if someone had dusted away the stars from that part of the sky. It is actually a number of overlapping dark dust clouds lying between us and the Milky Way's Sagittarius Arm, obscuring its stars from view.

2 The Cygnus Star Cloud

Running down the right-hand side of Cygnus, the Cygnus Star Cloud is a mass of faint stars very obvious to the naked eye under a dark sky. When we look towards it we are looking down the length of our own spiral arm within the Milky Way, where it begins to curve in towards the galaxy's centre. A pair of binoculars will show countless thousands of faint stars within it.

Delphinus

Vulpecula

Cygnus

Lyra

Sagitta

5 The Coathanger Cluster

Also known as 'Brocchi's Cluster', this is a cluster of around 40 faint stars, the brightest ten of which are arranged roughly in the shape of a coat hanger. It can be seen with the naked eye in a dark sky, but binoculars will highlight the differences in colour between the cluster's brightest stars.

4 Vega (Epsilon Lyrae)

Lying just over one-and-a-half degrees north of brilliant-blue Vega, Epsilon Lyrae is one of the most famous double stars in the sky. A pair of binoculars will show it as two stars of equal brightness very close together, and a telescope shows each of those stars is a double too - hence its nickname, 'the Double Double'.



Deep sky challenge

Autumn's fading galaxies

Winter is coming, but some of autumn's deep-sky treasures can still be enjoyed through your telescope

Sliding into November, it's only natural to swing your telescope away from the subtle attractions of the autumn sky and use it to enjoy views of winter's bigger, brighter and bolder objects. But before you start diving headfirst into the swirling grey and green gas clouds of the Orion Nebula (Messier 42) or squint at the Crab Nebula's (Messier 1) ghostly outline, why not postpone winter a little longer and give some of autumn's delights one last look?

If you can make it to somewhere with a dark sky unspoiled by light pollution, a small

telescope will show you the two small, faint satellite galaxies of the Andromeda Galaxy (Messier 31). Owners of larger instruments which can provide higher magnifications and gulp down more subtle starlight can see a nebula that is said to resemble a blue snowball, and a fine edge-on galaxy too.

Head over to Pegasus, the Winged Horse, and you will find the barred spiral galaxy NGC 7479. Glowing at a magnitude of +11.6, you'll need to be armed with a good-sized telescope to pick out its beautiful curved arms.



Blue Snowball Nebula
(NGC 7662)

“POSTPONE WINTER A LITTLE LONGER AND GIVE SOME OF AUTUMN’S DELIGHTS ONE LAST LOOK”

1 NGC 891

Small telescopes show this galaxy as a faint needle of light, but larger telescopes reveal it is an edge-on galaxy with a bright central bulge and a dark dust lane running across its equator. Higher magnification views will show mottling.

2 The Blue Snowball Nebula (NGC 7662)

Although this eighth-magnitude planetary nebula can be seen through small telescopes, its blue colour is only visible through instruments of six inches and larger.

3 Gamma Andromedae

One of the prettiest double stars in this region of the sky, Almach can be split with a small telescope, but larger instruments will highlight the beautiful contrast in colour between its bright pink-white component and its fainter, steely blue one.

4 Messier 110

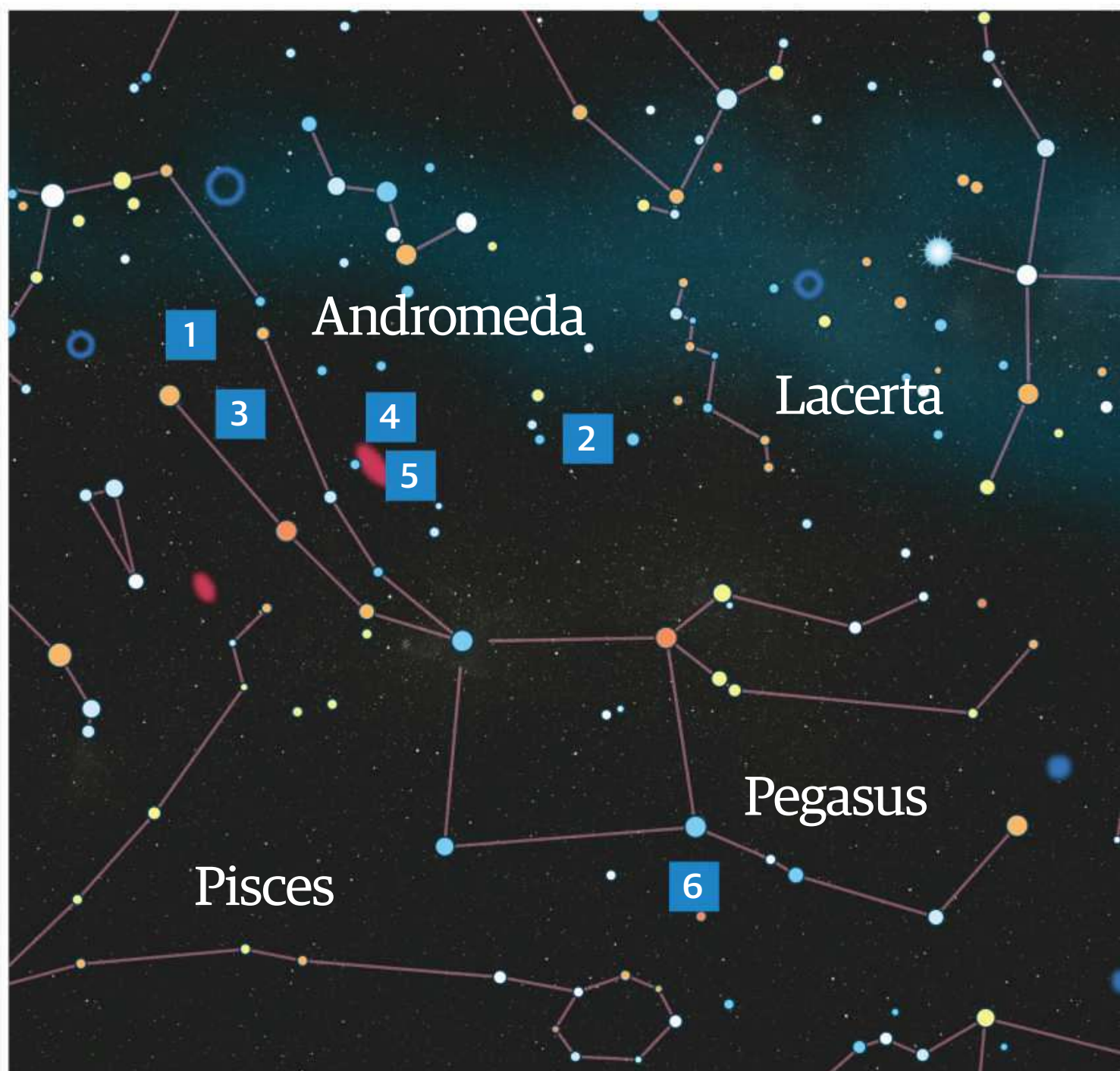
Lying so close to bright M31, it is almost lost in its parent galaxy’s glow, and it is usually overlooked. Small telescopes show it as a small misty smudge, while larger ones will show its subtle silvery beauty.

5 Messier 32

The smaller of M31’s satellite galaxies is visible in small telescopes as a slightly brighter smudge within that great galaxy, but larger telescopes pull it out from the background glow. It is an elliptical galaxy which shines at eighth magnitude.

6 NGC 7479

This very pretty barred spiral galaxy, presented almost face-on to us, is 11th magnitude so seeing its gracefully curved arms requires a large telescope under a dark sky. It is over 100 light years away.





The Northern Hemisphere

It's galaxies and globulars galore as we head into the cooler months

As we leave autumn and roll towards winter, the ever-darkening skies offer an impressive array of targets for those armed with binoculars, telescopes or even the unaided eye. This month the Sun has set by 18:00 and doesn't rise again until around 07:00 the following morning, giving astronomers a generous amount of time to explore the night sky.

Firm favourites Aquarius (the Water Bearer), Cepheus (the King) and Pegasus (the Winged Horse) bring the Great Pegasus Cluster (Messier 15) and spiral galaxies NGC 7331, NGC 7217 and NGC 7479 into view alongside the stunning Helix Nebula (NGC 7293), the Saturn Nebula (NGC 7009) and a gaggle of globular clusters.

Using the sky chart

This chart is for use at 22:00 (BST) mid-month and is set for 52° latitude.

- 01 Hold the chart above your head with the bottom of the page in front of you.
- 02 Face south and notice that north on the chart is behind you.
- 03 The constellations on the chart should now match what you see in the sky.



Magnitudes

- Sirius (-1.4)
- -0.5 to 0.0
- 0.0 to 0.5
- 0.5 to 1.0
- 1.0 to 1.5
- 1.5 to 2.0
- 2.0 to 2.5
- 2.5 to 3.0
- 3.0 to 3.5
- 3.5 to 4.0
- 4.0 to 4.5
- Fainter
- Variable star

Spectral types

- | | |
|-------|-----|
| • O-B | • G |
| • A | • K |
| • F | • M |

Deep-sky objects

- Open star clusters
- Globular star clusters
- Bright diffuse nebulae
- Planetary nebulae
- Galaxies

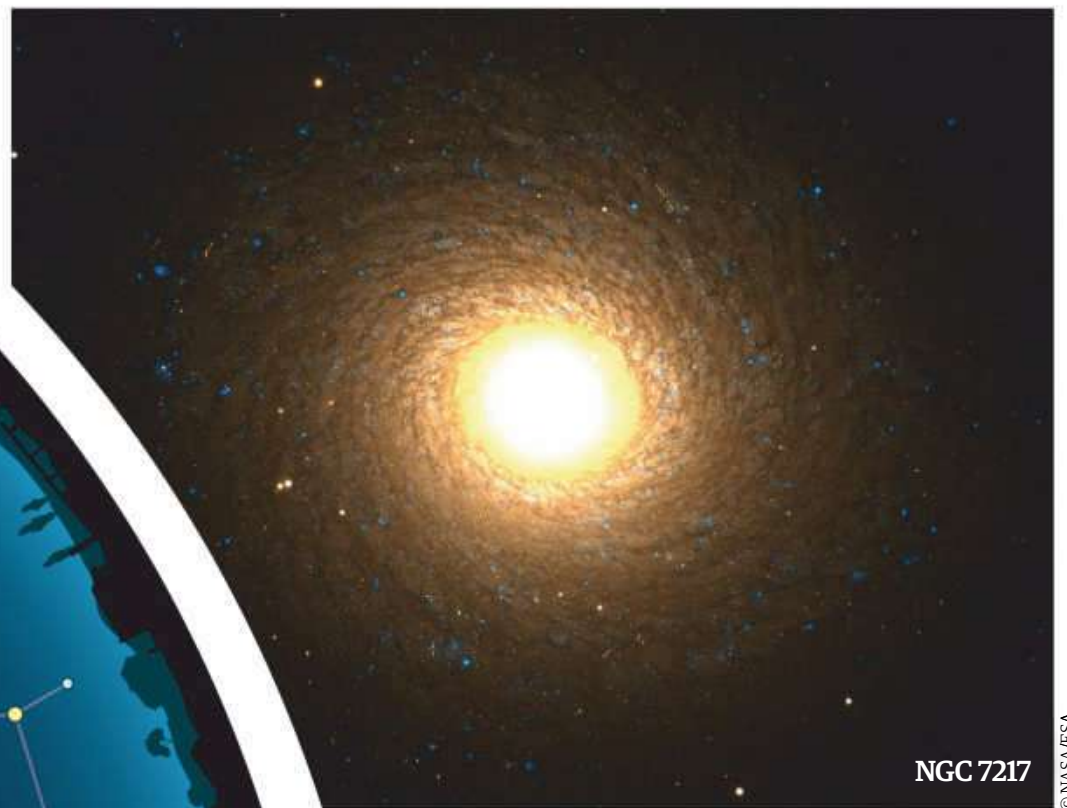


Observer's note:

The night sky as it appears on 17 October 2020 at approximately 22:00 (BST)

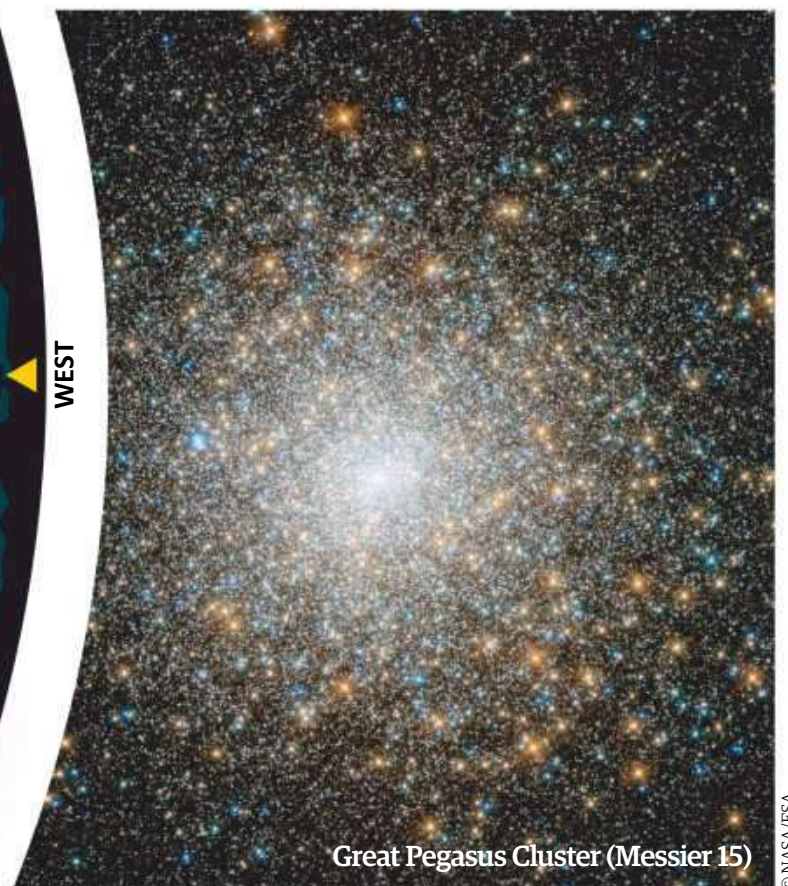


The Northern Hemisphere



NGC 7217

© NASA/ESA



Great Pegasus Cluster (Messier 15)

© NASA/ESA



Helix Nebula (NGC 7293)

© NASA/ESA



Vixen A70Lf with Mini Porta mount

An extremely affordable starter package that's easy to use and a breeze to set up

Telescope advice

Cost: £279.88 / \$369

From: Vixen Optics

Type: Refractor

Aperture: 2.8"

Focal length: 35.4"

Best for...



Beginners



Low budgets



Planetary viewing



Bright deep-sky objects

Vixen has kept the novice astronomer in mind, making the A70Lf a very portable 'grab-and-go' telescope that's no trouble transporting for a night of observations. The overall build of the A70Lf is of good quality for the price, with very good quality cast rings and a versatile Vixen dovetail, allowing you to fit the telescope tube to a variety of compatible mounts. The tripod legs of the Mini Porta mount are perhaps a bit too light, but seem to hold the tube steadily enough for observing, provided you have positioned the telescope on a level surface and treat the entire set-up with care.

Due to its small aperture the Vixen A70Lf is ideal for observing Solar System targets, as well as the lunar surface, and we were impressed with the views given the refractor's low price. The optical system provided very clear images, characteristic of the quality of a Vixen instrument. Observing in an area free of light pollution, we were able to test the abilities of the A70Lf combined with the supplied 20mm and 6.3mm Vixen Plössl eyepieces - which provided magnifications of 45x and 142x - to the maximum. Given that the useful magnification of the telescope is around 143x, we thought that pushing the telescope to such a high magnification using the 6.3mm eyepiece was perhaps a bit too optimistic - especially since the views through this eyepiece are not as clear.

Sadly the 6x24 finderscope does let the telescope down, meaning that anyone who is very unfamiliar with the night sky will struggle to observe with the A70Lf, despite it being aimed at beginners. Anyone who has used a telescope without the guidance of a finderscope will know how long it takes to eventually find the target they have been wanting to observe. We couldn't see any way of attaching a red dot finder due to a non-standard fitting, so it's likely that you would need to upgrade the A70Lf's finderscope altogether.

Bringing the view into focus did prove to be an effort with the 'toy-like' focuser. Even when we slowly and gently turned the focusing wheel, the image seemed to bounce around the field of view, making it difficult to tell whether the image was focused or not unless we stopped adjusting.

The Moon was in the sky, so we took advantage of observing its cratered surface and were very pleased with the A70Lf's clarity. Given that the telescope is an achromat and has a relatively long focal length, there isn't any pesky chromatic aberration, or colour-fringing, to speak of around bright objects such as our lunar companion or Jupiter, which we soon turned the scope towards.

Views of the gas giant were clear and we could just about make out the planet's bands, along with four of its Galilean moons - Io, Ganymede, Europa and Callisto. Turning the A70Lf to the Orion Nebula (M42), we could see the structure of this beautiful star-forming region very clearly, and the members of the Trapezium star cluster found at the nebula's heart were easy to see. Observing any deep-sky objects which are particularly diffuse and have a magnitude fainter than +4.0 is a struggle for this telescope due to its small aperture, and therefore its ability to collect enough light.

Despite its drawbacks, the Vixen A70Lf combined with the Mini Porta mount is versatile when it comes to accessorising with eyepieces, provided you don't push the refractor too close to its magnification limit. What's more - and provided you can find a higher quality finderscope - this refractor is an ideal telescope for children and novice astronomers given its ease of use and reasonable price for those on a budget.

Left: The Vixen A70Lf is compact, promoting a high degree of portability and making it ideal for beginners to astronomy





“DUE TO ITS SMALL APERTURE THE VIXEN A70Lf IS IDEAL FOR OBSERVING SOLAR SYSTEM TARGETS”

Main: The alt-azimuth mount is easy to use and seemed to move smoothly

Left: The image seemed to bounce around the field of view no matter how gently we used the focuser to bring our chosen target into sight

Below: Eyepieces with a focal length of 20mm and 6.3mm are supplied with the A70Lf

Satish Dhawan

He was a pioneer and innovator for Indian space science

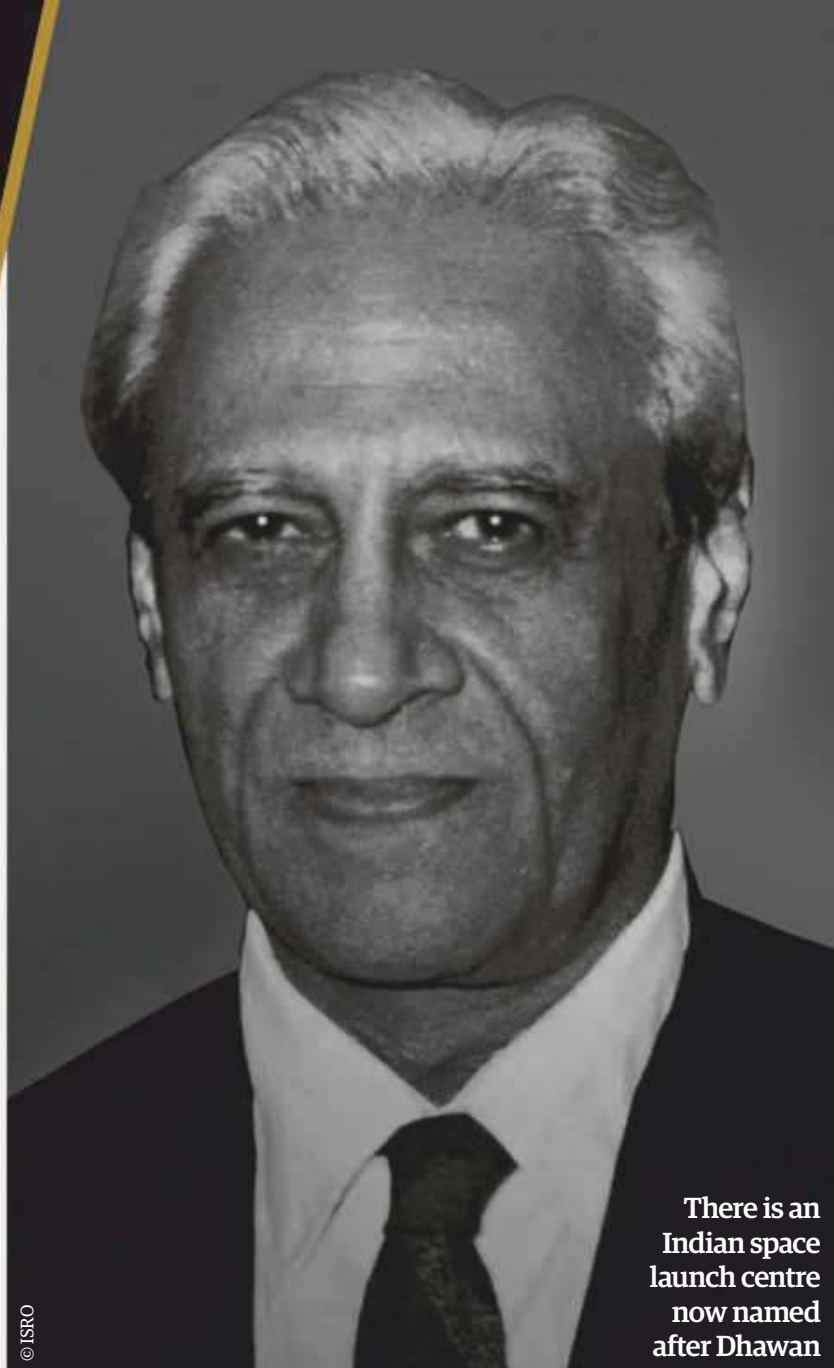
25 September 2020 was the 100th anniversary of the birth of famous Indian rocket scientist Professor Satish Dhawan. He is considered to be the father of experimental fluid dynamics research in India and was key in making the nation's space program what it is today.

Dhawan was born in Srinagar, India, and was well educated, with a peculiar array of qualifications gained from the University of Lahore, now in Pakistan. This includes a bachelor's degree in physics and mathematics and a master's degree in English literature, finished off with a bachelor's degree in mechanical engineering. His inquisitive academic nature then took him abroad to the US, where he received a master's degree in aeronautical engineering in Minneapolis and a PhD in aeronautics and mathematics from the California Institute of Technology (Caltech). It was here, under the tutelage of Hans W. Liepmann, where his interests in fluid dynamics peaked.

After his academic adventure in the US came to an end in 1951, Dhawan returned home and joined the Indian Institute of Science (IISc) as a scientific officer. After a decade of revolutionising engineering science and mechanics in the country, he became the institute's director. During this decade he masterminded the construction of the country's first high-speed aerodynamics and boundary layer laboratories, also managing to do so at a low cost.

In 1972 Dhawan became the third chairman of the Indian Space Research Organisation (ISRO), following on from the space agency's founder Vikram Sarabhai and Mambillikalathil Govind Kumar Menon. During his tenure as chairman, Dhawan was able to guide the space agency through a remarkable period of growth that benefitted the entire country.

This immense task required great leadership, coordination and an ability to raise senior staff to his high standards - both scientific and administrative. What followed was a period of evolution for Indian space science, and the ISRO was able to address nationwide issues with communication, meteorology and education, goals which the objective founder Sarabhai had outlined from the start.



There is an Indian space launch centre now named after Dhawan

"He masterminded the construction of the country's first boundary layer laboratory"

The Ariane Passenger Payload Experiment (APPLE), launched on 19 June 1981, was a particularly interesting project that demonstrates this progression. This payload provided the first invaluable opportunity to gain hands-on experience with a communications satellite in orbit around Earth, as well as relaying TV programmes and radio networking across the country. This received much praise, and the Indian prime minister at the time, Indira Gandhi, signified this as the 'dawn of India's satellite communication era'.

It is clear that wherever Dhawan went, he excelled at bringing a certain scientific standard and commitment with him. His contributions to science, centred around fluid dynamics research and aerospace engineering, were groundbreaking at the time, but his structural and organisational innovations and leadership qualities were equally as important. Now the Indian space agency has multiple satellites in low-Earth orbit, and even one around Mars.

For all his efforts, Dhawan received many awards, including the Padma Vibhushan - the country's second-highest civilian honour - and the Indira Gandhi Award for National Integration.

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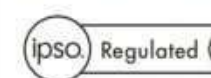


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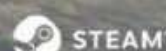
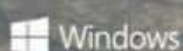
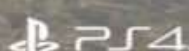
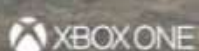
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Sky at Night
MAGAZINE
★★★★★
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